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KNOCK-LIMITED PERFORMANCE OF FUEL BLENDS CONTAINING
AROMATICS VI - 10 ALKYL BENZENES

By I. L. Drell and H. E. Alquist

Lewis Flight Propulsion Laboratory
Cleveland, Ohio



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KNOCK-LIMITED PERFORMANCE OF FUEL BLENDS CONTAINING AROMATICS

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SUMMARY

Knock-limited engine data are given for 10 aromatics, each in blends with base fuels. The aromatics are 1,2,3-trimethylbenzene, 1-ethyl-2-methylbenzene, o-diethylbenzene, 1,3-dimethyl-5-ethylbenzene, 1-ethyl-3-methylbenzene, p-diethylbenzene, 1,3,5-triethylbenzene, 1,3-diethyl-5-methylbenzene, 1-tert-butyl-3-methylbenzene, and 1-tert-butyl-4-methylbenzene. The engines used were the A.S.T.M. Aviation, A.S.T.M. Supercharge, a 17.6 engine (run at two inlet-air temperatures), and a modified CFR engine (run at five compression ratios).

The aromatic blends rated in about the order given (1,2,3-trimethylbenzene being poorest), considering the whole range of conditions studied. The three aromatics with ortho structures generally gave much lower blend knock ratings than the other seven aromatics. The differences within each group were not large.

A 25-percent blend of the better aromatics with a 120/110 base fuel raised both lean and rich performance numbers: A.S.T.M. Aviation values went up 5 percent or less; rich A.S.T.M. Supercharge values went up about 50 percent.

INTRODUCTION

A general investigation of the antiknock value of aromatic hydrocarbons as blending agents for aviation fuels has been made at the NACA Lewis laboratory. References 1 to 5 report the blend performance of benzene and 16 alkyl derivatives of benzene. The blend performance of the following 10 additional alkylbenzenes is reported herein:

1,2,3-Trimethylbenzene	1,3-Dimethyl-5-ethylbenzene
1-Ethyl-2-methylbenzene	1,3-Diethyl-5-methylbenzene
<u>o</u> -Diethylbenzene	1,3,5-Triethylbenzene
<u>p</u> -Diethylbenzene	1- <u>tert</u> -Butyl-3-methylbenzene
1-Ethyl-3-methylbenzene	1- <u>tert</u> -Butyl-4-methylbenzene

Relative knock-limited power, fuel-air mixture response, temperature sensitivity, and lead susceptibility are discussed. A.S.T.M. Aviation, A.S.T.M. Supercharge, and 17.6-engine data are given, as in references 1 to 5. (In these references, CFR designations F-3 and F-4 are used for the A.S.T.M. Aviation and A.S.T.M. Supercharge engines, respectively.) In addition, compression temperature-density data from a modified CFR engine operated at five compression ratios are included. These data give further information on fuel sensitivity to changes in engine severity.

The present test program was simplified over the previous program (references 1 to 5) in the following respects: Fewer blends were run in the small-scale engines; and full-scale single-cylinder studies were eliminated. The wide range of small-scale-engine conditions should give a fairly adequate measure of anti-knock value.

FUELS

The aromatic hydrocarbons were synthesized and purified at the NACA Lewis laboratory. Table I gives carbon structures and physical constants for the 10 alkylbenzenes. These aromatics were estimated to be at least 98-percent pure. In order to prevent peroxidation, 0.0002 pound of inhibitor per gallon was added. The first three aromatics listed in the table have a molecular structure containing an ortho arrangement. For brevity, they are called ortho aromatics herein.

Each aromatic was blended to a concentration of 25 percent by volume with a mixed base fuel; the mixed base fuel was 87.5 percent S reference fuel and 12.5 percent n-heptane; all components had 4 ml TEL per gallon. The 25-percent blends were run in the A.S.T.M. Aviation, A.S.T.M. Supercharge, 17.6, and modified CFR engines.

Each aromatic was also blended to a concentration of 20 percent by volume with S reference fuel. These blends were prepared

without lead and also with 4 ml TEL per gallon and were run in the A.S.T.M. Aviation and 17.6 engines only. The S reference fuel (essentially isooctane) used in the three base fuels was S-4.

PROCEDURE

The A.S.T.M. Aviation engine and procedure used are as specified in A.S.T.M. procedure D 614 (reference 6).

The A.S.T.M. Supercharge engine ("package unit") used herein, conforms to A.S.T.M. procedure D 909. Incipient knock, however, was used instead of the standard light-audible knock level. The incipient knock was detected by a magnetostriction internal pickup and a cathode-ray oscilloscope. For the investigations reported in references 1 to 5, another A.S.T.M. Supercharge engine (not a package unit) was used. (References 1 to 5 used the CFR designations of F-3 and F-4 for the A.S.T.M. Aviation and A.S.T.M. Supercharge engines, respectively.)

The supercharged 17.6 engine and the procedure used are described in reference 1. Operating conditions are presented in the present report in the figures which show the 17.6-engine performance.

The modified CFR supercharged engine used for the temperature-density investigation has a four-hole cylinder, dual ignition, shrouded intake valve, and pressurized-water coolant system. Operating conditions for this engine were: engine speed, 1800 rpm; spark advance, 20° B.T.C.; inlet-air temperature, 250° F; outlet coolant temperature, 250° F; and compression ratios, 5, 6, 7.3, 8.7, and 10. Incipient knock was detected by a magnetostriction internal pickup and a cathode-ray oscilloscope.

RESULTS AND DISCUSSION

A.S.T.M. Aviation engine data. - Table II gives A.S.T.M. Aviation ratings in terms of TEL in S reference fuel or octane number. The corresponding performance numbers are also listed. In all three base fuels, the ortho aromatics gave lower A.S.T.M. Aviation ratings than the other seven aromatics. Similarly, o-xylene (reference 2) and 1,2,4-trimethylbenzene (reference 3) gave low knock ratings.

The mixed base fuel has an A.S.T.M. Aviation rating of 120 performance number, a fairly high value for these severe conditions.

In the case of the three ortho aromatics, adding 25 percent to the mixed base fuel lowered the A.S.T.M. Aviation rating considerably. In the case of the other seven aromatics, the A.S.T.M. Aviation rating stayed about the same or went up slightly (5 percent or less).

Adding 20 percent aromatic to S reference fuel, leaded or unleaded, lowered the A.S.T.M. Aviation rating in all cases.

A.S.T.M. Supercharge engine data. - Knock-limited mixture-response data from the A.S.T.M. Supercharge engine are presented in figure 1. The fuels are leaded blends containing 25 percent of aromatic with the mixed base fuel. The data in each part of all the figures in this report were obtained in a single day, with few exceptions. Curves are included for the mixed base fuel and for S reference fuel plus 4 ml TEL per gallon.

The A.S.T.M. Supercharge ratings are also given in table II in terms of leaded S reference fuel in leaded *n*-heptane and the corresponding performance numbers. These ratings were obtained from reciprocal imep plots and a conversion chart, as described in reference 5. Table III gives imep ratios of blend relative to base fuel at various fuel-air ratios.

The A.S.T.M. Supercharge knock values, like the A.S.T.M. Aviation values, divided into two distinct groups. The three ortho aromatics had low values and the other seven aromatics, high values. Differences within each group were relatively small in most cases. Of the three ortho aromatics, 1,2,3-trimethylbenzene gave the lowest blend ratings; there was little difference between the 1-ethyl-2-methylbenzene and *o*-diethylbenzene blends. The 1,2,3-trimethylbenzene blend was poorer than the mixed base fuel at all fuel-air ratios. The other two ortho-aromatic blends were poorer than the base fuel at lean mixtures but were somewhat better than the base fuel at rich mixtures.

The seven high-performance aromatics gave practically equal blend ratings at lean fuel-air ratios. At rich fuel-air ratios, 1-*tert*-butyl-4-methylbenzene seemed to be slightly better than the others and *p*-diethylbenzene slightly poorer than the rest. For these seven aromatics, adding 25 percent to the mixed base fuel raised both lean and rich knock values in the A.S.T.M. Supercharge engine: the knock-limited power went up 7 to 11 percent at a fuel-air ratio of 0.065, and 45 to 53 percent at a fuel-air ratio of 0.11.

17.6-engine data. - Knock-limited mixture-response data from the 17.6 engine are presented in figures 2 to 4: figure 2 is for leaded 25-percent aromatic blends with the mixed base fuel; figure 3 is for leaded 20-percent blends with S reference fuel; and figure 4 is for unleaded 20-percent blends with S reference fuel. Table III gives imep ratios of blend relative to base fuel at five fuel-air ratios.

At all the 17.6-engine conditions, the blends containing 1,2,3-trimethylbenzene generally gave the lowest knock values. The 1-ethyl-2-methylbenzene blend was next, and the *o*-diethylbenzene blend gave the highest knock values of the three ortho aromatics.

The other seven aromatics gave considerably higher knock values. The blends containing 1-*tert*-butyl-4-methylbenzene and 1-*tert*-butyl-3-methylbenzene had approximately equal knock values at all the 17.6-engine conditions. These aromatics were among the poorer of the seven at the most mild conditions (100° F inlet air, rich); but they were generally among the better fuels at the least mild conditions (250° F inlet air, lean).

The blends containing 1,3,5-triethylbenzene and 1,3-diethyl-5-methylbenzene were among the better fuels at most of the 17.6-engine conditions; 1,3-dimethyl-5-ethylbenzene was usually one of the poorest of the seven aromatics. The blends containing 1-ethyl-3-methylbenzene and *p*-diethylbenzene generally fell in between the extremes.

Definitions and values of relative temperature sensitivity and lead susceptibility for 20-percent blends with S reference fuel are given in table IV. The aromatic blends were, in general, more sensitive than S reference fuel to changes of inlet-air temperature in the 17.6 engine. At a fuel-air ratio of 0.07, the blends containing the seven high-performance aromatics averaged about 18 percent greater temperature sensitivity than S reference fuel. The over-all order of temperature sensitivity at 17.6-engine conditions for the blends containing these seven aromatics appeared to be as follows: 1-*tert*-butyl-3-methylbenzene (least sensitive), 1-*tert*-butyl-4-methylbenzene, 1-ethyl-3-methylbenzene, *p*-diethylbenzene, 1,3-dimethyl-5-ethylbenzene, 1,3-diethyl-5-methylbenzene, and 1,3,5-triethylbenzene (most sensitive). The ortho-aromatic blends were only slightly more temperature sensitive than S reference fuel.

The 17.6-engine lead-susceptibility values for the blends containing 1,2,3-trimethylbenzene and 1-ethyl-2-methylbenzene were

smaller than for S reference fuel. (o-Xylene (reference 2) and 1,2,4-trimethylbenzene (reference 3) had similarly given low lead susceptibilities.) The values for the o-diethylbenzene blend were, in general, about the same as for S reference fuel. The lead susceptibilities for the seven high-performance-aromatic blends were greater: at a fuel-air ratio of 0.07, they averaged about 12 percent greater than S reference fuel; at a fuel-air ratio of 0.11, they averaged about 5 percent greater than S reference fuel.

Relative lead susceptibilities were also computed for the same 20-percent blends under the A.S.T.M. Aviation engine conditions; performance numbers from table II were used in place of imep values in the equation at the bottom of table IV. The A.S.T.M. Aviation lead susceptibilities of the aromatic blends were all lower than that for S reference fuel. Values ranged from 0.88 for 1,2,3-trimethylbenzene to 0.99 for 1-tert-butyl-3-methylbenzene. For the seven high-performance aromatic blends, the average value was 0.97.

Modified-CFR-engine data. - Knock-limited mixture-response data from the modified CFR engine at five compression ratios are presented in figure 5. The fuels are leaded 25-percent aromatic blends with the mixed base fuel. Air-flow values are included in addition to the customary imep, isfc, and inlet-air-pressure values.

From these data, compression-air densities and temperatures were computed and are plotted against fuel-air ratio in the three-dimensional plots of figure 6. The compression densities and temperatures were computed by the following formulas:

$$\rho = \frac{A (r-1)}{n v_d}$$

$$T = T_0 r^{\gamma-1}$$

where

ρ compression-air density, pounds per cubic inch

A air flow, pounds per minute

r compression ratio

- n intake cycles per minute
 v_d displacement volume, cubic inches
 T compression-air temperature, $^{\circ}\text{R}$
 T_0 inlet-air temperature, $^{\circ}\text{R}$
 γ ratio of specific heats for air, 1.4

The formulas are from references 7 and 8, which demonstrate their use in correlating the effects of compression ratio and inlet-air temperature on knock limit.

The aromatic blends are presented in approximately the order of increasing knock limit in figures 5 and 6, considering the whole range of conditions shown. In figure 6, the severest conditions are at the highest compression temperatures and approximately stoichiometric fuel-air ratios (near 0.07). The mildest conditions are at the lowest compression temperatures and highest fuel-air ratios.

The slope at any point on the surface for a given fuel in figure 6 is a measure of the fuel sensitivity at those conditions; the slope at constant fuel-air ratio is a measure of sensitivity to temperature changes; the slope at constant compression temperature is a measure of sensitivity to changes in fuel-air ratio (or, as it is usually called, mixture response). A comparison of the slopes in figure 6 shows that all the aromatic blends were generally more sensitive than the paraffinic base fuel.

The three ortho-aromatic blends (figs. 6(a) to 6(c)) were, in general, less sensitive to changes of temperature and fuel-air ratio than the others. The 1-ethyl-2-methylbenzene blend (fig. 6(b)) was perhaps the least sensitive. Among the seven high-performance aromatics, the p-diethylbenzene blend (fig. 6(f)) was generally the least temperature sensitive; however, it had high mixture response.

The 1,3-diethyl-5-methylbenzene blend (fig. 6(h)) had definitely higher knock limit than the base fuel over the whole range of conditions investigated. At very severe conditions, it had the highest knock limit of the 10 aromatic blends. It seemed to be less temperature- and mixture-sensitive than the 1,3,5-triethylbenzene blend (fig. 6(g)) at very severe conditions but more sensitive than this fuel at mild conditions.

The 1-tert-butyl-3-methylbenzene blend (fig. 6(i)) had smaller temperature sensitivity than the 1-tert-butyl-4-methylbenzene blend (fig. 6(j)) at rich mixtures; at lean mixtures, the situation was reversed. The 1-tert-butyl-4-methylbenzene blend had somewhat greater mixture response over most of the range.

SUMMARY OF RESULTS

The knock-limited blend performance in small-scale engines was determined for the following 10 alkylbenzenes:

1,2,3-Trimethylbenzene	1,3-Dimethyl-5-ethylbenzene
1-Ethyl-2-methylbenzene	1,3-Diethyl-5-methylbenzene
<u>o</u> -Diethylbenzene	1,3,5-Triethylbenzene
<u>p</u> -Diethylbenzene	1- <u>tert</u> -Butyl-3-methylbenzene
1-Ethyl-3-methylbenzene	1- <u>tert</u> -Butyl-4-methylbenzene

The following results were obtained:

1. The three aromatics with ortho structures generally gave considerably lower knock ratings in blends than the seven other aromatics. The 1,2,3-trimethylbenzene blends had the lowest knock limits at nearly all the conditions investigated.

2. The seven other aromatics did not differ greatly in blend ratings at most conditions. Their addition in 25-percent concentration to the mixed base fuel raised both A.S.T.M. Aviation and A.S.T.M. Supercharge ratings. A.S.T.M. Aviation performance numbers went up only slightly, with a maximum of 5 percent for the 1,3-diethyl-5-methylbenzene blend. In the A.S.T.M. Supercharge engine, at a fuel-air ratio of 0.065, the knock-limited power went up by amounts varying from 7 to 11 percent; at a fuel-air ratio of 0.11, the knock-limited power went up by amounts varying from 45 to 53 percent. The 1-tert-butyl-4-methylbenzene blend had the highest A.S.T.M. Supercharge rich rating.

3. The aromatic blends were all more sensitive to changes of temperature and fuel-air ratio than the paraffinic base fuels. At very severe conditions (modified CFR engine), the mixed base fuel had an equal or higher knock limit than all the 25-percent aromatic blends except the 1,3-diethyl-5-methylbenzene blend.

4. Under 17.6-engine conditions, the seven high-performance aromatics in 20-percent blends with S reference fuel had lead

susceptibilities greater than that of S reference fuel; they were greater by an average of 12 percent at a fuel-air ratio of 0.07, and 5 percent at a fuel-air ratio of 0.11. Under A.S.T.M. Aviation conditions, the same blends averaged 3 percent smaller lead susceptibility than S reference fuel.

Lewis Flight Propulsion Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio, June 10, 1949.

REFERENCES

1. Meyer, Carl L., and Branstetter, J. Robert: The Knock-Limited Performance of Fuel Blends Containing Aromatics. I - Toluene, Ethylbenzene, and p-Xylene. NACA ARR E4J05, 1944.
2. Branstetter, J. Robert, and Meyer, Carl L.: The Knock-Limited Performance of Fuel Blends Containing Aromatics. II - Iso-propylbenzene, Benzene, and o-Xylene. NACA ARR E5A20, 1945.
3. Meyer, Carl L., and Branstetter, J. Robert: The Knock-Limited Performance of Fuel Blends Containing Aromatics. III - 1,3,5-Trimethylbenzene, tert-Butylbenzene, and 1,2,4-Trimethylbenzene. NACA ARR E5D16, 1945.
4. Meyer, Carl L., and Branstetter, J. Robert: The Knock-Limited Performance of Fuel Blends Containing Aromatics. IV - Data for m-Diethylbenzene, 1-Ethyl-4-methylbenzene, and sec-Butylbenzene Together with a Summarization of Data for 12 Aromatic Hydrocarbons. NACA ARR E5D16a, 1945.
5. Meyer, Carl L., and Branstetter, J. Robert: The Knock-Limited Performance of Fuel Blends Containing Aromatics. V - n-Propylbenzene, n-Butylbenzene, Isobutylbenzene, m-Xylene, and 1-Iso-propyl-4-methylbenzene. NACA ARR E6C05, 1946.
6. Anon.: ASTM Manual of Engine Test Methods for Rating Fuels. A.S.T.M. (Phildelphia), 1948.
7. Evvard, John C., and Branstetter, J. Robert: A Correlation of the Effects of Compression Ratio and Inlet-Air Temperature on the Knock Limits of Aviation Fuels in a CFR Engine - I. NACA ACR E5D20, 1945.

8. Alquist, Henry E., O'Dell, Leon, and Evvard, John C.: A Correlation of the Effects of Compression Ratio and Inlet-Air Temperature on the Knock Limits of Aviation Fuels in a CFR Engine - II. NACA ARR E6E13, 1946.

TABLE I - PHYSICAL CONSTANTS OF 10 ALKYL BENZENES (ENGINE SAMPLES)

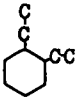
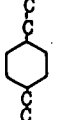
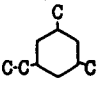
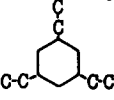
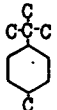
Alkylbenzene	Carbon structure	Freezing point (°C)	Boiling point (°C)	Index of refraction n_D^{20}	Density at 20° C (gram/ml)
1,2,3-Trimethylbenzene		-25.97	176.1	1.5137	0.8945
1-Ethyl-2-methylbenzene		-80.94	165.1	1.5045	.8807
<u>o</u> -Diethylbenzene		-32.05	183.2	1.5032	.8797
<u>p</u> -Diethylbenzene		-43.31	183.7	1.4948	.8621
1-Ethyl-3-methylbenzene		-95.62	161.3	1.4965	.8645
1,3-Dimethyl-5-ethylbenzene		-84.43	183.6	1.4980	.8647
1,3-Diethyl-5-methylbenzene		-74.01	200.6	1.4969	.8633
1,3,5-Triethylbenzene		-66.44	215.9	1.4957	.8620
1- <u>tert</u> -Butyl-3-methylbenzene		-41.53	189.2	1.4945	.8658
1- <u>tert</u> -Butyl-4-methylbenzene		-52.73	192.6	1.4919	.8612



TABLE II - A.S.T.M. AVIATION AND A.S.T.M. SUPERCHARGE ENGINE RATINGS OF AROMATIC BLENDS

Aromatic in blend	Blend composition (percent by volume)		A.S.T.M. Aviation ratings		A.S.T.M. Supercharge ratings		
			TEL (ml/ gal)	Performance number	Lean		Rich (fuel-air ratio, 0.11)
	Aromatic S refer- ence fuel	87.5 per- cent S + 12.5 per- cent n-heptane			S + 4 ml TEL/gal in n-heptane + 4 ml TEL/gal (percent)	Performance number	
(87.5 percent S + 12.5 percent n-heptane)	0	100	4	120	87.5	116	87.5
1,2,3-Trimethylbenzene	25	75	4	105	76.5	96	84.0
1-Ethyl-2-methylbenzene				120	79.0	101	91.5
o-Diethylbenzene				107	84.0	109	91.5
p-Diethylbenzene				119	91.8	127	>100
1-Ethyl-3-methylbenzene				124	92.5	129	>100
1,3-Dimethyl-5-ethylbenzene				124	91.0	125	>100
1,3-Diethyl-5-methylbenzene				126	92.5	129	>100
1,3,5-Triethylbenzene				122	91.0	125	>100
1-tert-Butyl-3-methylbenzene				125	92.5	129	>100
1-tert-Butyl-4-methylbenzene				124	92.5	129	>100
1,2,3-Trimethylbenzene	20	0	4	115			
1-Ethyl-2-methylbenzene				123			
o-Diethylbenzene				125			
p-Diethylbenzene				136			
1-Ethyl-3-methylbenzene				141			
1,3-Dimethyl-5-ethylbenzene				140			
1,3-Diethyl-5-methylbenzene				140			
1,3,5-Triethylbenzene				140			
1-tert-Butyl-3-methylbenzene				141			
1-tert-Butyl-4-methylbenzene				142			
1,2,3-Trimethylbenzene	20	0	0	85			
1-Ethyl-2-methylbenzene				86			
o-Diethylbenzene				84			
p-Diethylbenzene				94			
1-Ethyl-3-methylbenzene				95			
1,3-Dimethyl-5-ethylbenzene				95			
1,3-Diethyl-5-methylbenzene				95			
1,3,5-Triethylbenzene				93			
1-tert-Butyl-3-methylbenzene				93			
1-tert-Butyl-4-methylbenzene				97			

^a Estimated performance number = $\frac{\text{imep of aromatic blend}}{\text{imep of S + 4 ml TEL/gal}} \times \text{performance number of S + 4 ml TEL/gal}$.

^b Octane number.



TABLE III - KNOCK-LIMITED IMEP RATIOS OF AROMATIC BLENDS IN A.S.T.M. SUPERCHARGE ENGINE AND 17.6 ENGINE

Aromatic in blend with base fuel	imep ratio of blend relative to base fuel (for three base fuels, values are average imep in lb/sq in.)									
	Fuel-air ratio									
	0.065	0.07	0.085	0.10	0.11	0.065	0.07	0.085	0.10	0.11
Leaded 25-percent blends with mixed base fuel	A.S.T.M. Supercharge engine					17.6 engine; inlet-air temperature, 250° F				
Base fuel (87.5 percent S + 12.5 percent n-heptane + 4 ml TEL/gal)	132	139	157	169	172	178	180	191	196	195
1,2,3-Trimethylbenzene	0.82	0.85	0.90	0.93	0.94	0.94	0.94	0.99	0.98	0.99
1-Ethyl-2-methylbenzene	.86	.91	1.03	1.08	1.09	1.02	1.06	1.09	1.06	1.05
o-Diethylbenzene	.93	.96	1.01	1.04	1.07	1.07	1.11	1.14	1.14	1.13
p-Diethylbenzene	1.10	1.13	1.22	1.34	1.45	1.43	1.50	1.57	1.55	1.52
1-Ethyl-3-methylbenzene	1.11	1.14	1.28	1.40	1.47	1.34	1.43	1.54	1.56	1.57
1,3-Dimethyl-5-ethylbenzene	1.07	1.11	1.28	1.41	1.49	1.36	1.45	1.49	1.49	1.47
1,3-Diethyl-5-methylbenzene	1.10	1.15	1.27	1.39	1.50	1.44	1.50	1.65	1.71	1.69
1,3,5-Triethylbenzene	1.07	1.11	1.25	1.40	1.51	1.44	1.51	1.62	1.63	1.60
1-tert-Butyl-3-methylbenzene	1.10	1.15	1.28	1.40	1.49	1.40	1.44	1.52	1.55	1.50
1-tert-Butyl-4-methylbenzene	1.11	1.14	1.28	1.43	1.53	1.44	1.49	1.57	1.59	1.57
Leaded 20-percent blends with S reference fuel	17.6 engine; inlet-air temperature, 100° F					17.6 engine; inlet-air temperature, 250° F				
Base fuel (S + 4 ml TEL/gal)	299	294	292	287	283	253	254	266	272	271
1,2,3-Trimethylbenzene	0.87	0.88	0.90	0.93	0.94	0.83	0.87	0.90	0.89	0.91
1-Ethyl-2-methylbenzene	1.00	1.00	1.01	1.00	.99	.96	1.00	1.03	1.01	.98
o-Diethylbenzene	1.11	1.10	1.11	1.10	1.08	1.00	1.03	1.07	1.11	1.10
p-Diethylbenzene	1.40	1.47	1.53	1.49	1.47	1.25	1.27	1.32	1.42	1.45
1-Ethyl-3-methylbenzene	1.42	1.46	1.52	1.48	1.47	1.26	1.32	1.39	1.46	1.46
1,3-Dimethyl-5-ethylbenzene	1.39	1.46	1.53	1.46	1.43	1.17	1.24	1.35	1.38	1.38
1,3-Diethyl-5-methylbenzene	1.47	1.54	1.59	1.56	1.54	1.22	1.25	1.36	1.44	1.50
1,3,5-Triethylbenzene	1.49	1.58	1.59	1.53	1.53	1.20	1.24	1.36	1.49	1.51
1-tert-Butyl-3-methylbenzene	1.36	1.40	1.45	1.47	1.45	1.22	1.23	1.32	1.41	1.42
1-tert-Butyl-4-methylbenzene	1.37	1.40	1.44	1.45	1.45	1.23	1.25	1.32	1.36	1.36
Unleaded 20-percent blends with S reference fuel	17.6 engine; inlet-air temperature, 100° F					17.6 engine; inlet-air temperature, 250° F				
Base fuel (S reference fuel)	192	186	185	188	190	161	160	169	179	181
1,2,3-Trimethylbenzene	1.04	1.03	1.05	1.07	1.09	0.97	0.97	0.99	1.00	1.02
1-Ethyl-2-methylbenzene	1.03	1.04	1.09	1.08	1.10	1.03	1.01	1.03	1.07	1.10
o-Diethylbenzene	1.04	1.06	1.11	1.11	1.12	1.03	1.01	1.03	1.08	1.11
p-Diethylbenzene	1.32	1.33	1.41	1.44	1.41	1.11	1.12	1.23	1.34	1.41
1-Ethyl-3-methylbenzene	1.28	1.31	1.39	1.41	1.43	1.11	1.11	1.21	1.29	1.33
1,3-Dimethyl-5-ethylbenzene	1.24	1.26	1.31	1.35	1.32	1.10	1.07	1.17	1.24	1.29
1,3-Diethyl-5-methylbenzene	1.30	1.36	1.48	1.51	1.51	1.10	1.11	1.23	1.36	1.44
1,3,5-Triethylbenzene	1.35	1.37	1.46	1.50	1.48	1.09	1.09	1.19	1.31	1.42
1-tert-Butyl-3-methylbenzene	1.30	1.33	1.37	1.39	1.38	1.16	1.16	1.26	1.36	1.37
1-tert-Butyl-4-methylbenzene	1.31	1.32	1.37	1.40	1.38	1.12	1.14	1.22	1.31	1.37

TABLE IV - INLET-AIR TEMPERATURE SENSITIVITY AND LEAD SUSCEPTIBILITY OF 20-PERCENT AROMATIC BLENDS WITH S REFERENCE FUEL IN 17.6 ENGINE

[Compression ratio, 7.0; engine speed, 1800 rpm; spark advance, 30° B.T.C.; coolant, water at 212° F; incipient knock]

Aromatic in 20-percent blend with S reference fuel	Inlet-air temperature sensitivity and lead susceptibility of blend relative to base fuel									
	Fuel-air ratio									
	0.065	0.07	0.085	0.10	0.11	0.065	0.07	0.085	0.10	0.11
	Relative temperature sensitivity ^a									
	Unloaded blends					Leaded blends (4 ml/gal)				
1,2,3-Trimethylbenzene	1.07	1.07	1.06	1.07	1.07	1.04	1.01	0.99	1.04	1.04
1-Ethyl-2-methylbenzene	1.00	1.03	1.06	1.01	1.00	1.04	1.01	.98	.98	1.00
o-Diethylbenzene	1.01	1.04	1.08	1.02	1.01	1.12	1.07	1.04	.99	.98
p-Diethylbenzene	1.19	1.19	1.15	1.08	1.00	1.12	1.16	1.15	1.05	1.01
1-Ethyl-3-methylbenzene	1.15	1.18	1.15	1.09	1.07	1.13	1.11	1.10	1.02	1.01
1,3-Dimethyl-5-ethylbenzene	1.13	1.17	1.13	1.09	1.03	1.19	1.18	1.13	1.06	1.03
1,3-Diethyl-5-methylbenzene	1.19	1.22	1.20	1.11	1.05	1.21	1.23	1.17	1.08	1.02
1,3,5-Triethylbenzene	1.23	1.26	1.23	1.14	1.04	1.24	1.27	1.17	1.02	1.01
1-tert-Butyl-3-methylbenzene	1.12	1.15	1.09	1.02	1.01	1.11	1.13	1.10	1.04	1.02
1-tert-Butyl-4-methylbenzene	1.17	1.16	1.12	1.06	1.01	1.11	1.12	1.09	1.06	1.06
	Relative lead susceptibility ^b									
	Inlet-air temperature, 100° F					Inlet-air temperature, 250° F				
	0.84	0.85	0.85	0.86	0.86	0.86	0.89	0.91	0.89	0.89
1,2,3-Trimethylbenzene	.97	.96	.92	.92	.90	.94	.98	1.00	.95	.90
1-Ethyl-2-methylbenzene	1.07	1.04	1.00	.99	.96	.97	1.02	1.04	1.02	.99
o-Diethylbenzene	1.06	1.11	1.08	1.03	1.04	1.13	1.13	1.08	1.06	1.03
p-Diethylbenzene	1.11	1.12	1.09	1.05	1.03	1.13	1.19	1.14	1.13	1.10
1-Ethyl-3-methylbenzene	1.11	1.16	1.16	1.08	1.08	1.06	1.15	1.16	1.12	1.07
1,3-Dimethyl-5-ethylbenzene	1.13	1.14	1.08	1.03	1.02	1.11	1.13	1.11	1.06	1.05
1,3-Diethyl-5-methylbenzene	1.10	1.15	1.09	1.02	1.04	1.10	1.14	1.14	1.14	1.07
1,3,5-Triethylbenzene	1.05	1.05	1.06	1.06	1.06	1.05	1.07	1.05	1.04	1.04
1-tert-Butyl-3-methylbenzene	1.05	1.06	1.05	1.04	1.05	1.10	1.10	1.08	1.03	1.00
1-tert-Butyl-4-methylbenzene										

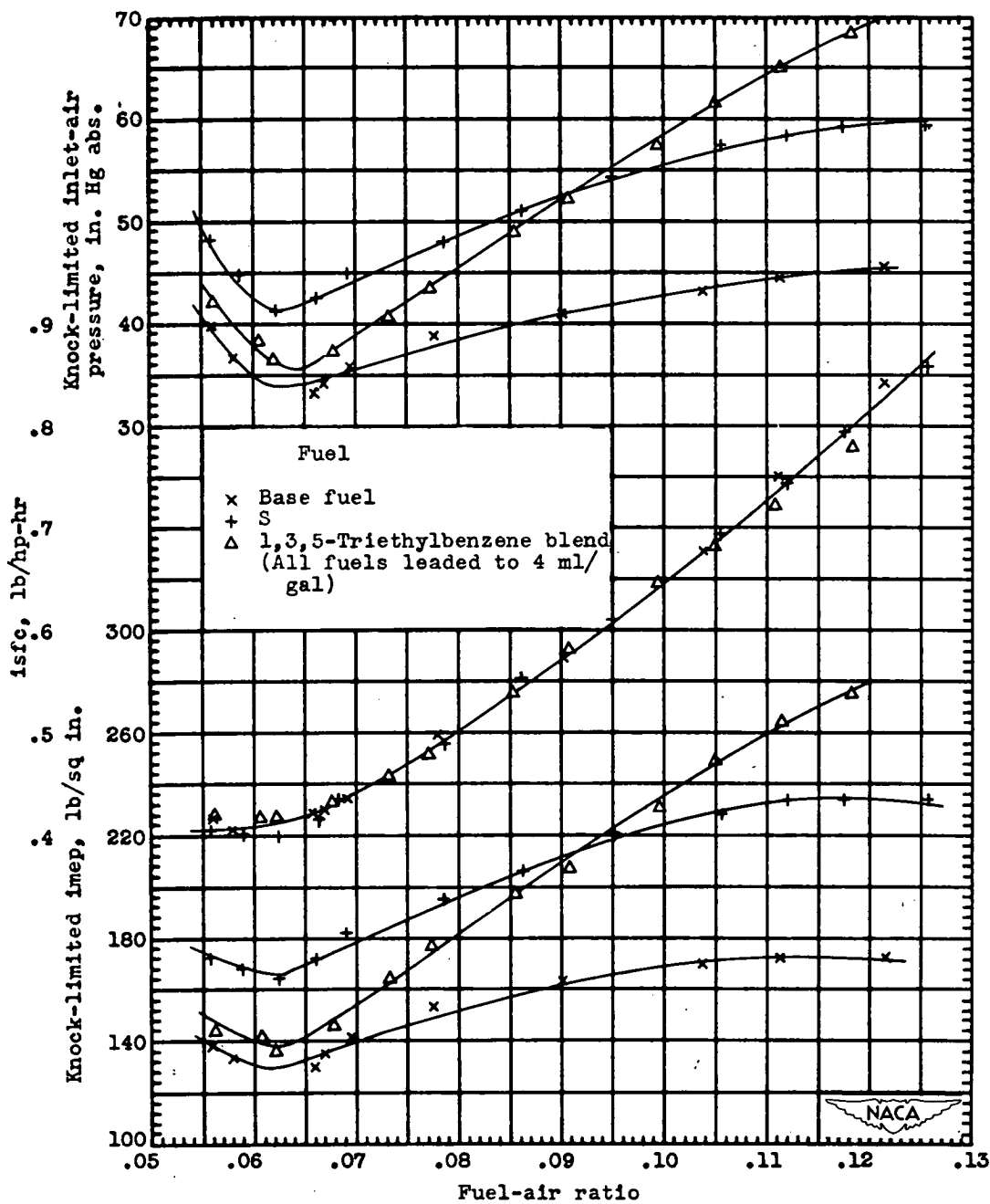
$$^a \text{Relative temperature sensitivity} = \frac{\text{Blend imep (100° F air)}}{\text{Blend imep (250° F air)}} = \frac{\text{imep ratio (100° F air)}}{\text{imep ratio (250° F air)}}$$

$$= \frac{\text{Base-fuel imep (100° F air)}}{\text{Base-fuel imep (250° F air)}}$$

$$^b \text{Relative lead susceptibility} = \frac{\text{Blend imep (4 ml TEL/gal)}}{\text{Blend imep (0 ml TEL/gal)}} = \frac{\text{imep ratio (4 ml TEL/gal)}}{\text{imep ratio (0 ml TEL/gal)}}$$

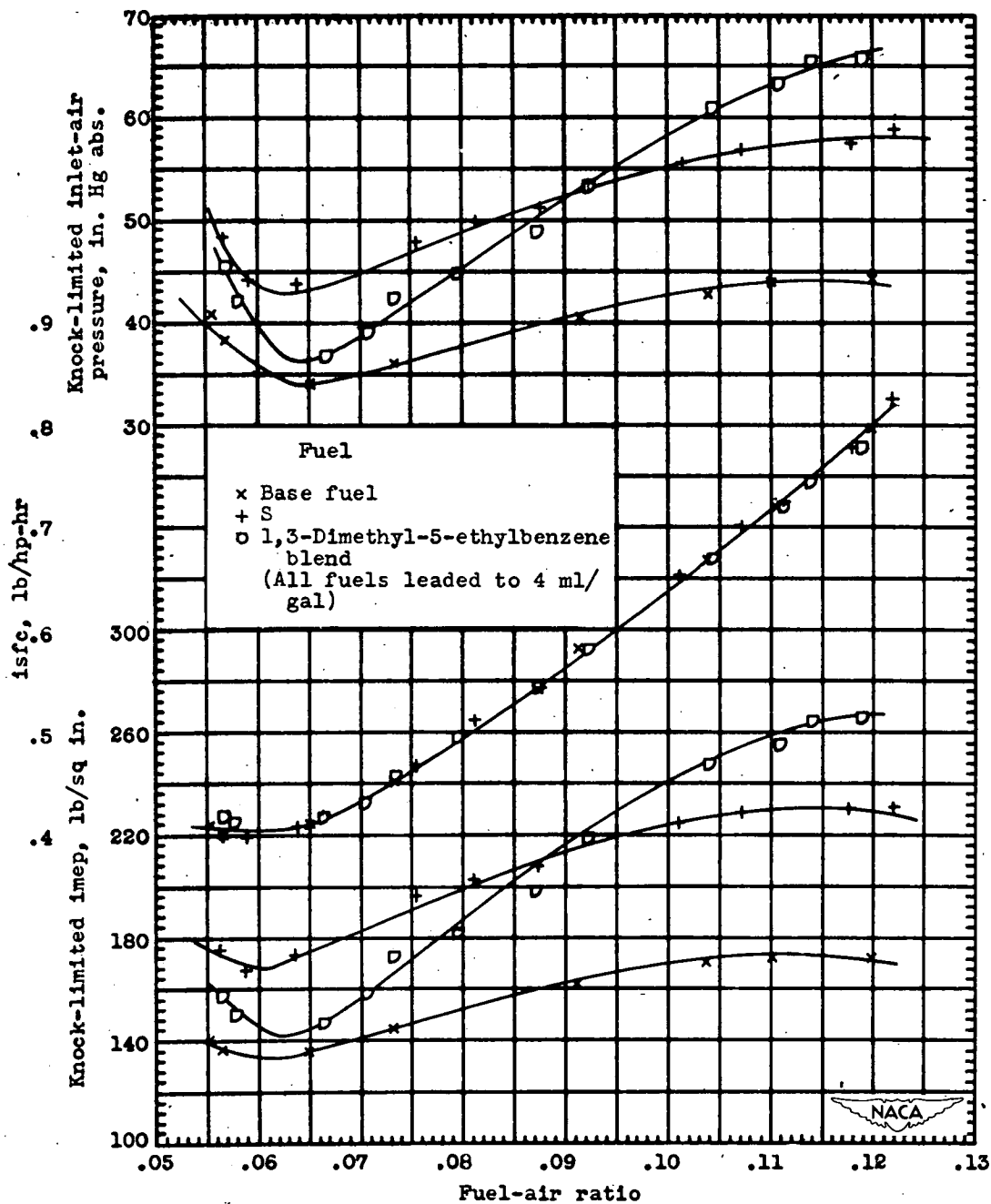
$$= \frac{\text{Base-fuel imep (4 ml TEL/gal)}}{\text{Base-fuel imep (0 ml TEL/gal)}}$$

NACA



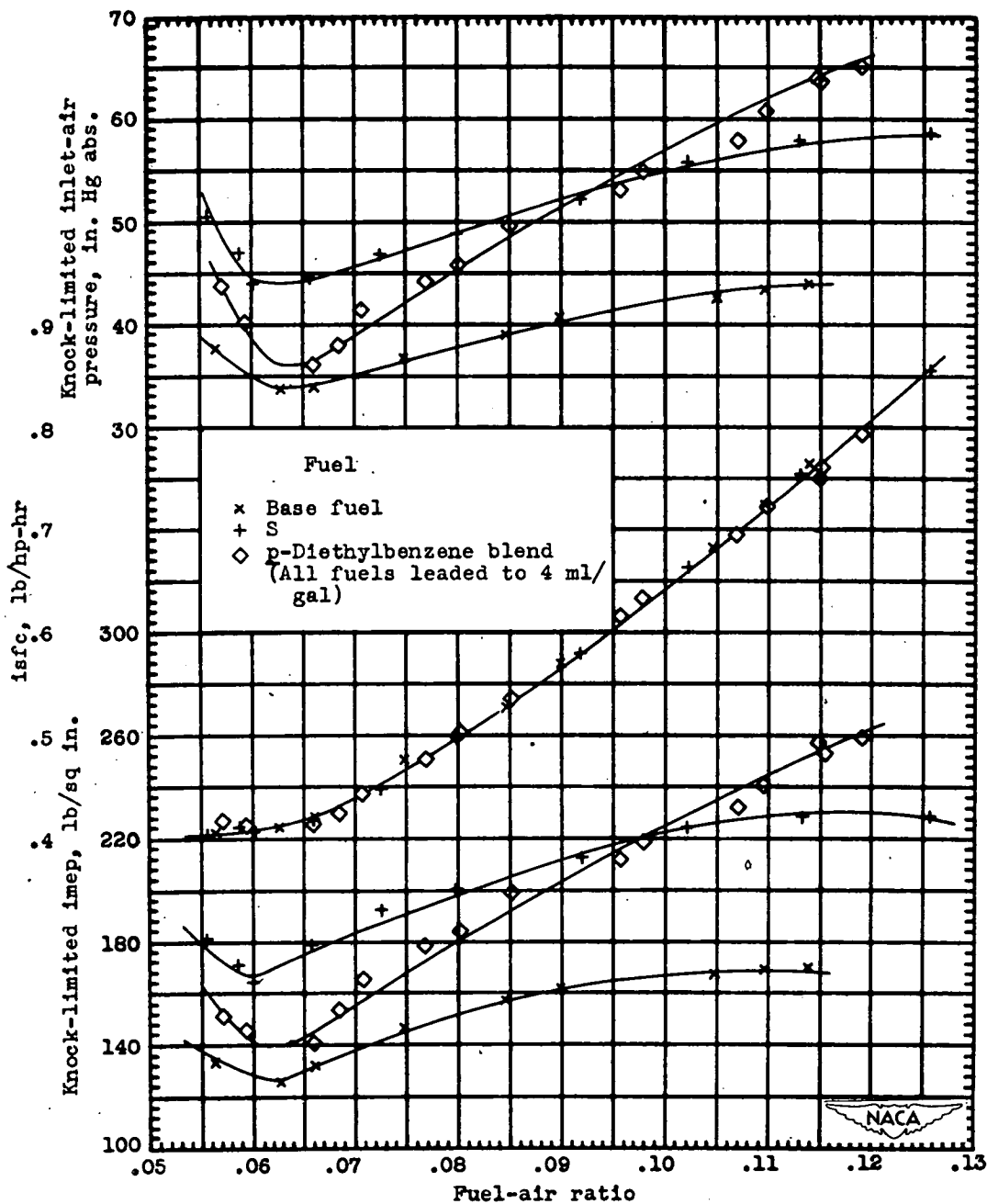
(a) 1,3,5-Triethylbenzene.

Figure 1. - Performance of leaded 25-percent aromatic blends with base fuel consisting of 87.5 percent S reference fuel and 12.5 percent *n*-heptane plus 4 ml TEL per gallon in A.S.T.M. Supercharge engine. Incipient knock.



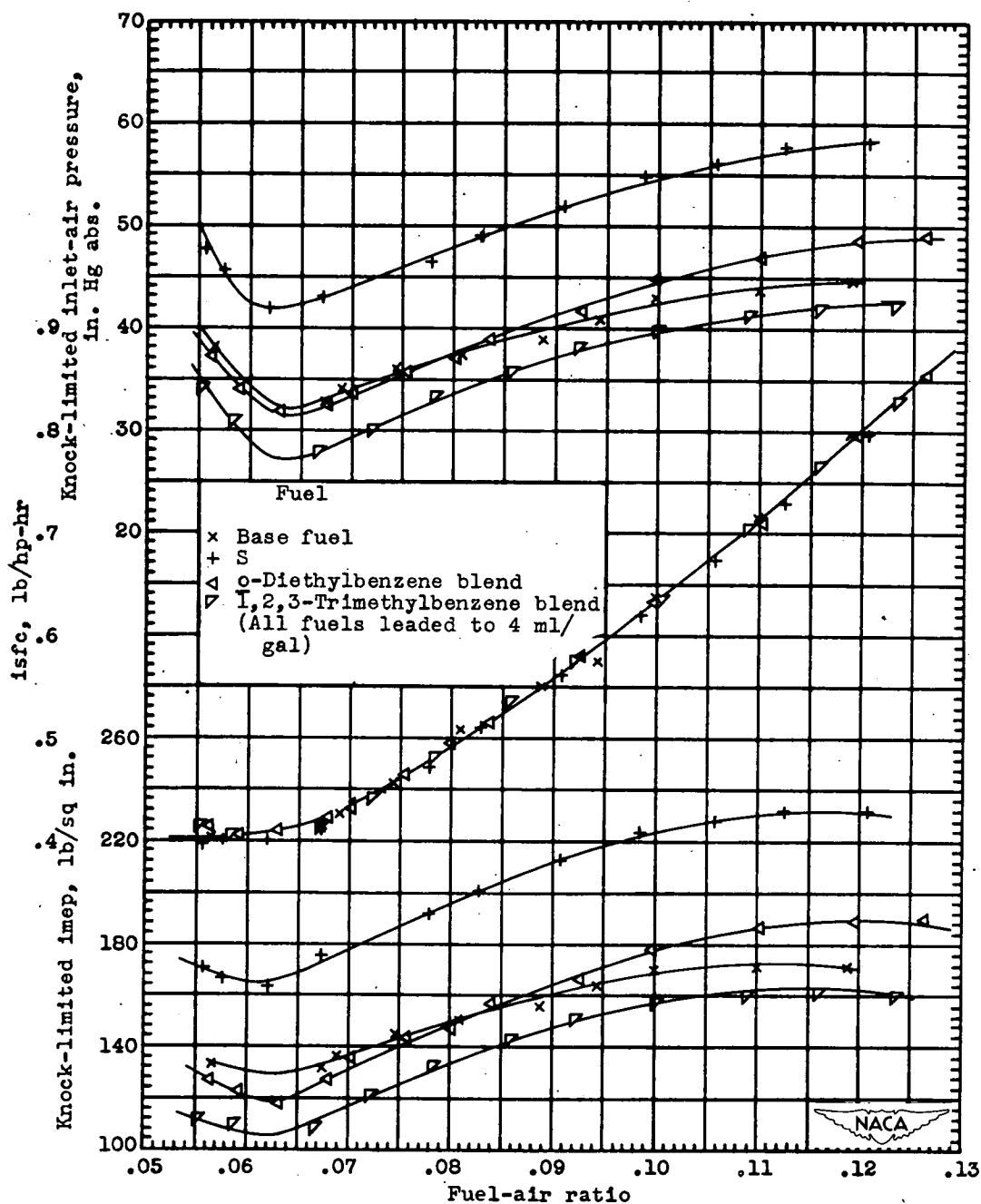
(b) 1,3-Dimethyl-5-ethylbenzene.

Figure 1. - Continued. Performance of leaded 25-percent aromatic blends with base fuel consisting of 87.5 percent S reference fuel and 12.5 percent n-heptane plus 4 ml TEL per gallon in A.S.T.M. Supercharge engine. Incipient knock.



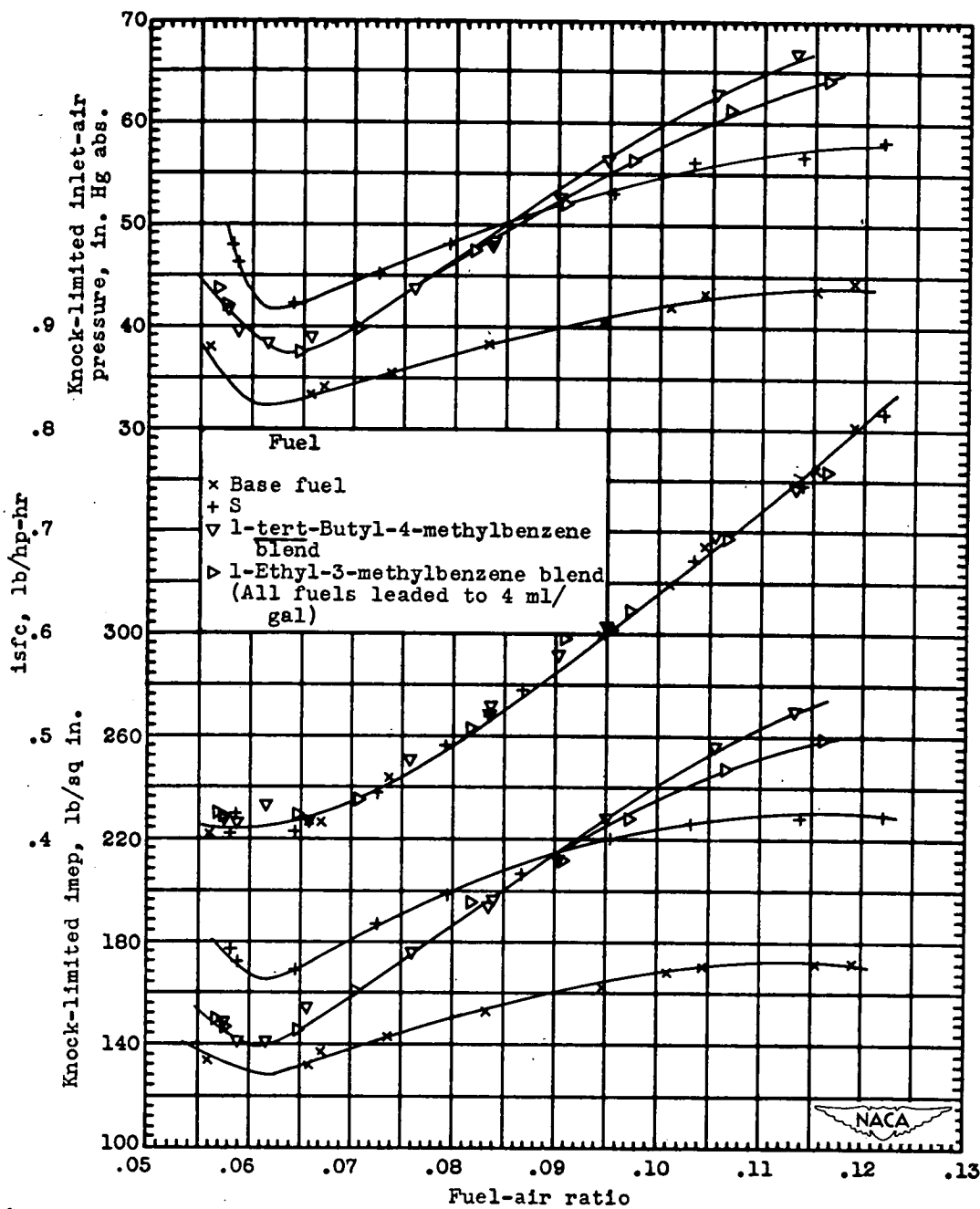
(c) p-Diethylbenzene.

Figure 1. - Continued. Performance of leaded 25-percent aromatic blends with base fuel consisting of 87.5 percent S reference fuel and 12.5 percent *n*-heptane plus 4 ml TEL per gallon in A.S.T.M. Supercharge engine. Incipient knock.



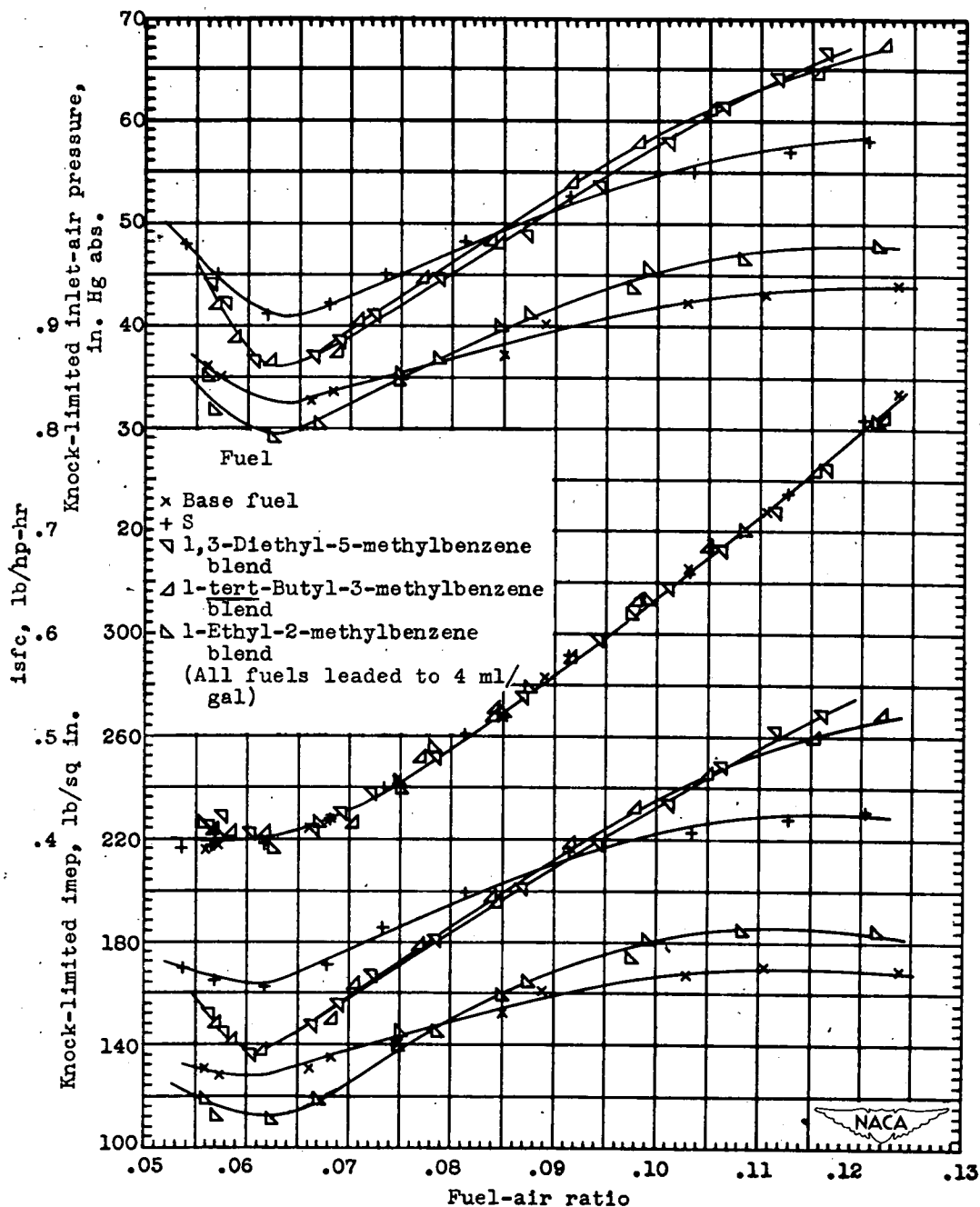
(d) *o*-Diethylbenzene; 1,2,3-trimethylbenzene.

Figure 1. - Continued. Performance of leaded 25-percent aromatic blends with base fuel consisting of 87.5 percent S reference fuel and 12.5 percent *n*-heptane plus 4 ml TEL per gallon in A.S.T.M. Supercharge engine. Incipient knock.



(e) 1-Ethyl-3-methylbenzene; 1-tert-butyl-4-methylbenzene.

Figure 1. - Continued. Performance of leaded 25-percent aromatic blends with base fuel consisting of 87.5 percent S reference fuel and 12.5 percent n-heptane plus 4 ml TEL per gallon in A.S.T.M. Supercharge engine. Incipient knock.



(f) 1-Ethyl-2-methylbenzene; 1-tert-butyl-3-methylbenzene; 1,3-diethyl-5-methylbenzene.

Figure 1. - Concluded. Performance of leaded 25-percent aromatic blends with base fuel consisting of 87.5 percent S reference fuel and 12.5 percent *n*-heptane plus 4 ml TEL per gallon in A.S.T.M. Supercharge engine. Incipient knock.

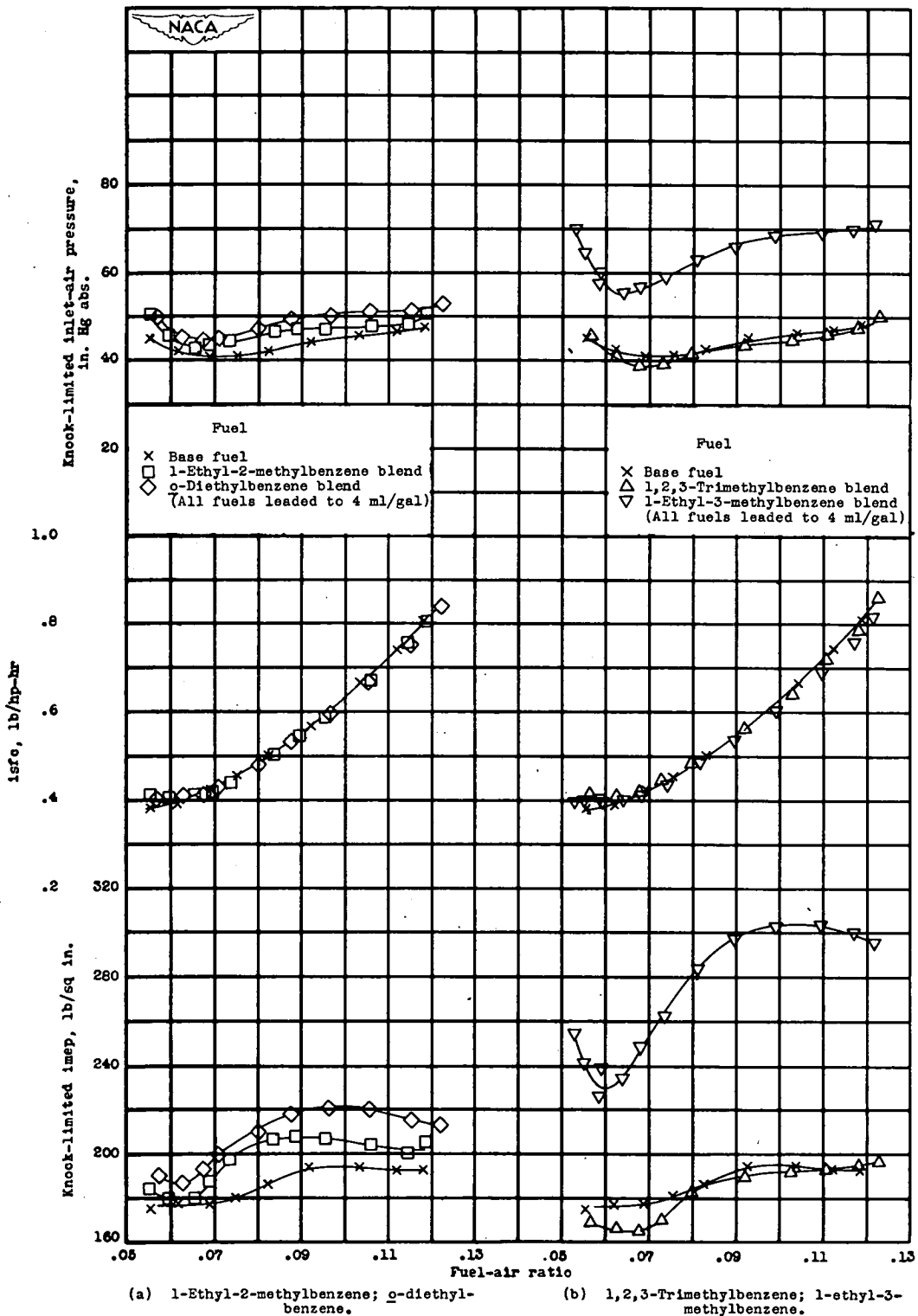


Figure 2. - Performance of leaded 25-percent aromatic blends with base fuel consisting of 87.5 percent 8 reference fuel and 12.5 percent n-heptane plus 4 ml TEL per gallon in 17.6 engine. Compression ratio, 7.0; engine speed, 1800 rpm; spark advance, 30° B.T.C.; coolant, water at 212° F; inlet-air temperature, 250° F; incipient knock.

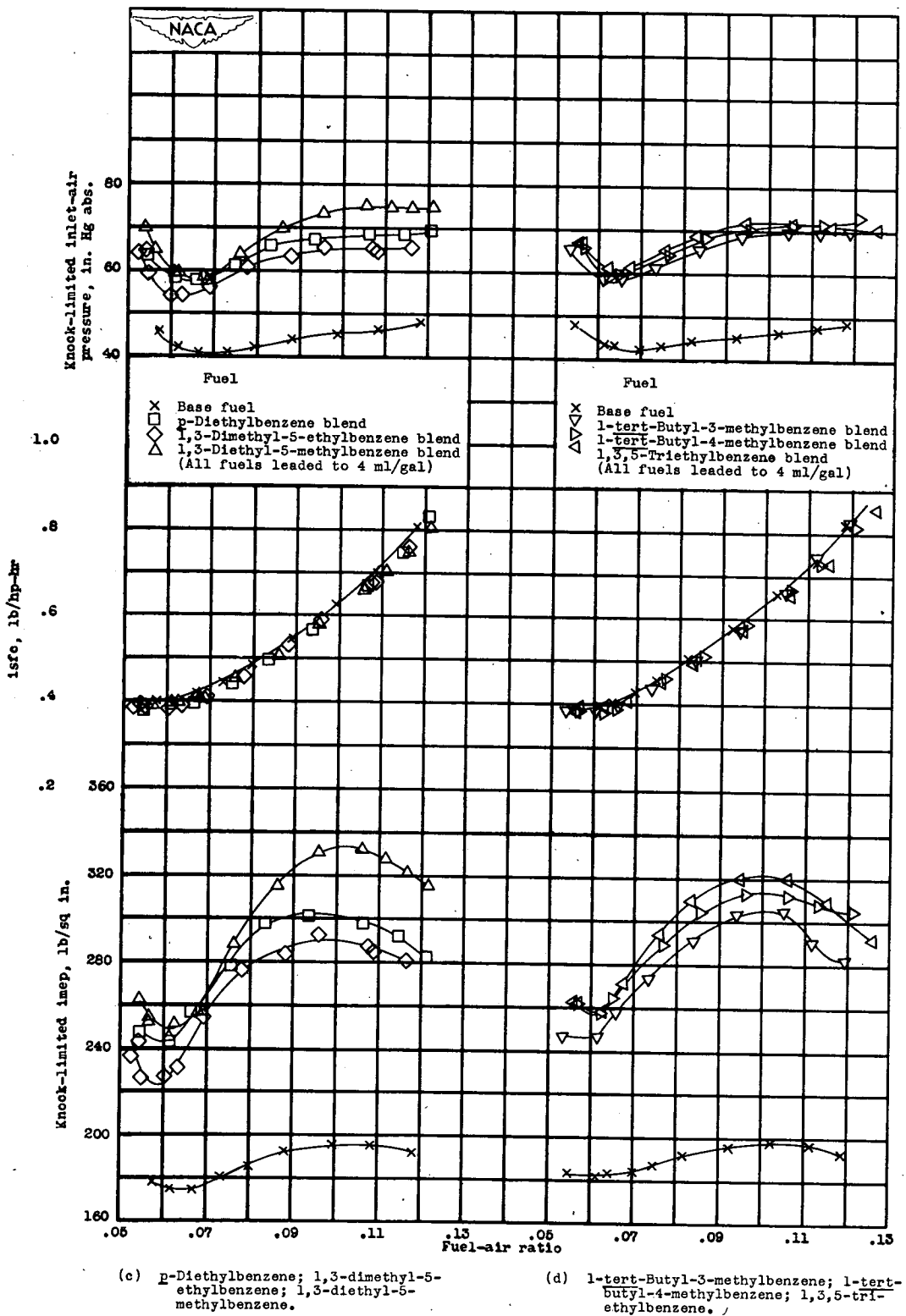
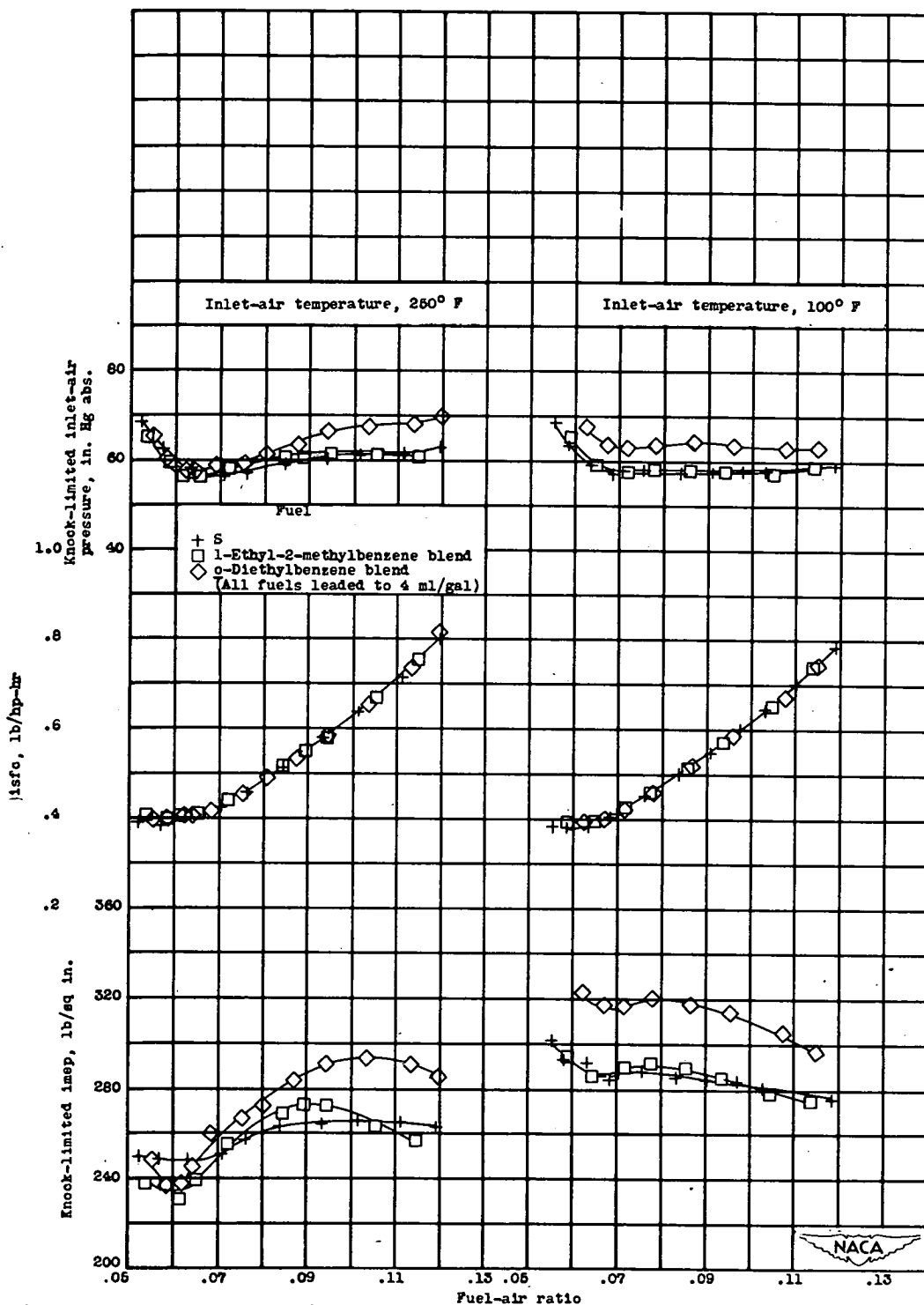
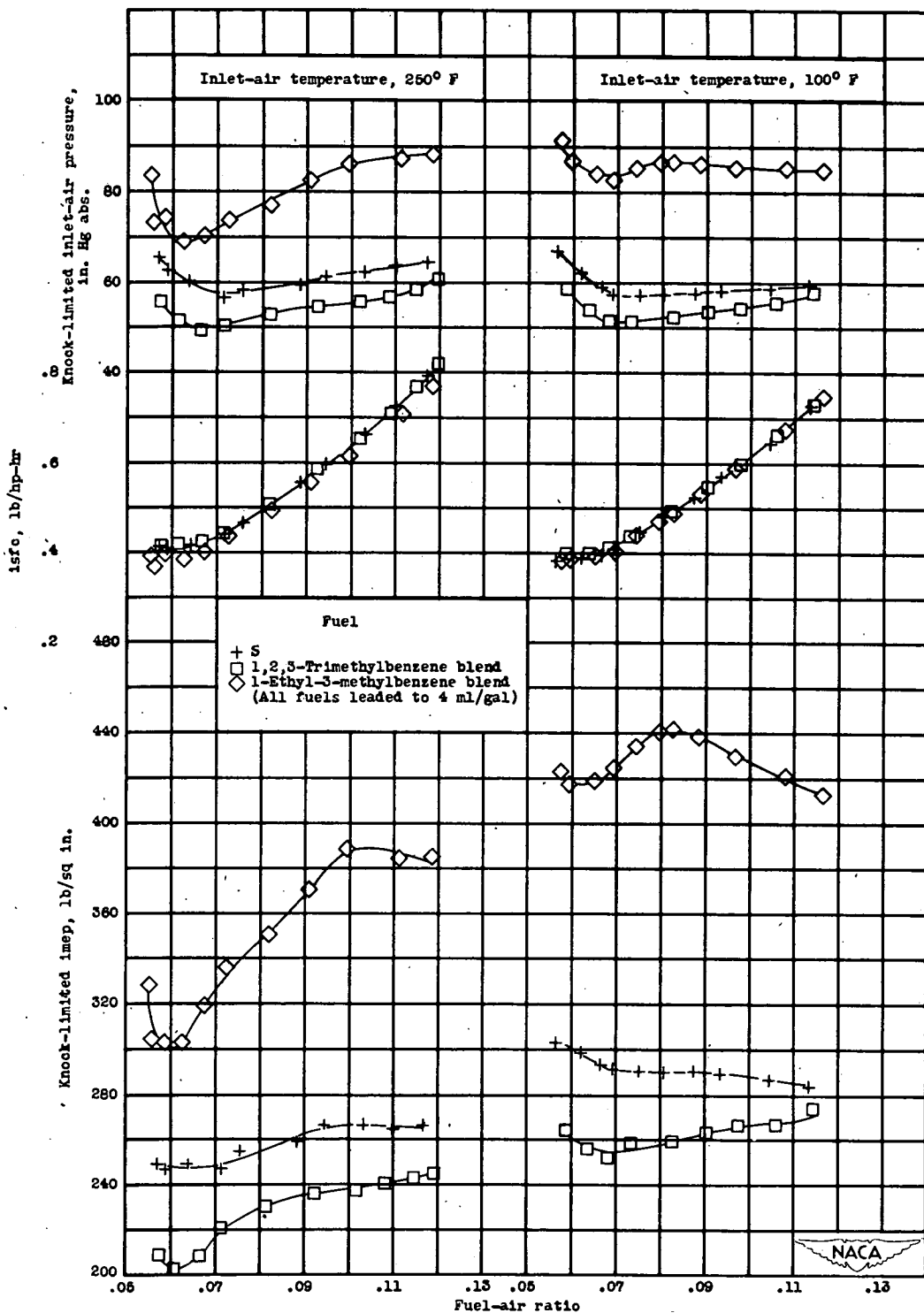


Figure 2. - Concluded. Performance of leaded 25-percent aromatic blends with base fuel consisting of 87.5 percent S reference fuel and 12.5 percent n-heptane, plus 4 ml TEL per gallon in 17.6 engine. Compression ratio, 7.0; engine speed, 1800 rpm; spark advance, 30° B.T.C.; coolant, water at 212° F; inlet-air temperature, 250° F; incipient knock.



(a) 1-Ethyl-2-methylbenzene; o-diethylbenzene.

Figure 3. - Performance of leaded 20-percent aromatic blends with S reference fuel plus 4 ml TEL per gallon in 17.6 engine. Compression ratio, 7.0; engine speed, 1800 rpm; spark advance, 30° B.T.C.; coolant, water at 212° F; incipient knock.



(b) 1,2,3-Trimethylbenzene; 1-ethyl-3-methylbenzene.
 Figure 3. - Continued. Performance of leaded 20-percent aromatic blends with 5 reference fuel plus 4 ml TEL per gallon in 17.6 engine. Compression ratio, 7.0; engine speed, 1800 rpm; spark advance, 30° B.T.C. coolant, water at 212° F; incipient knock.

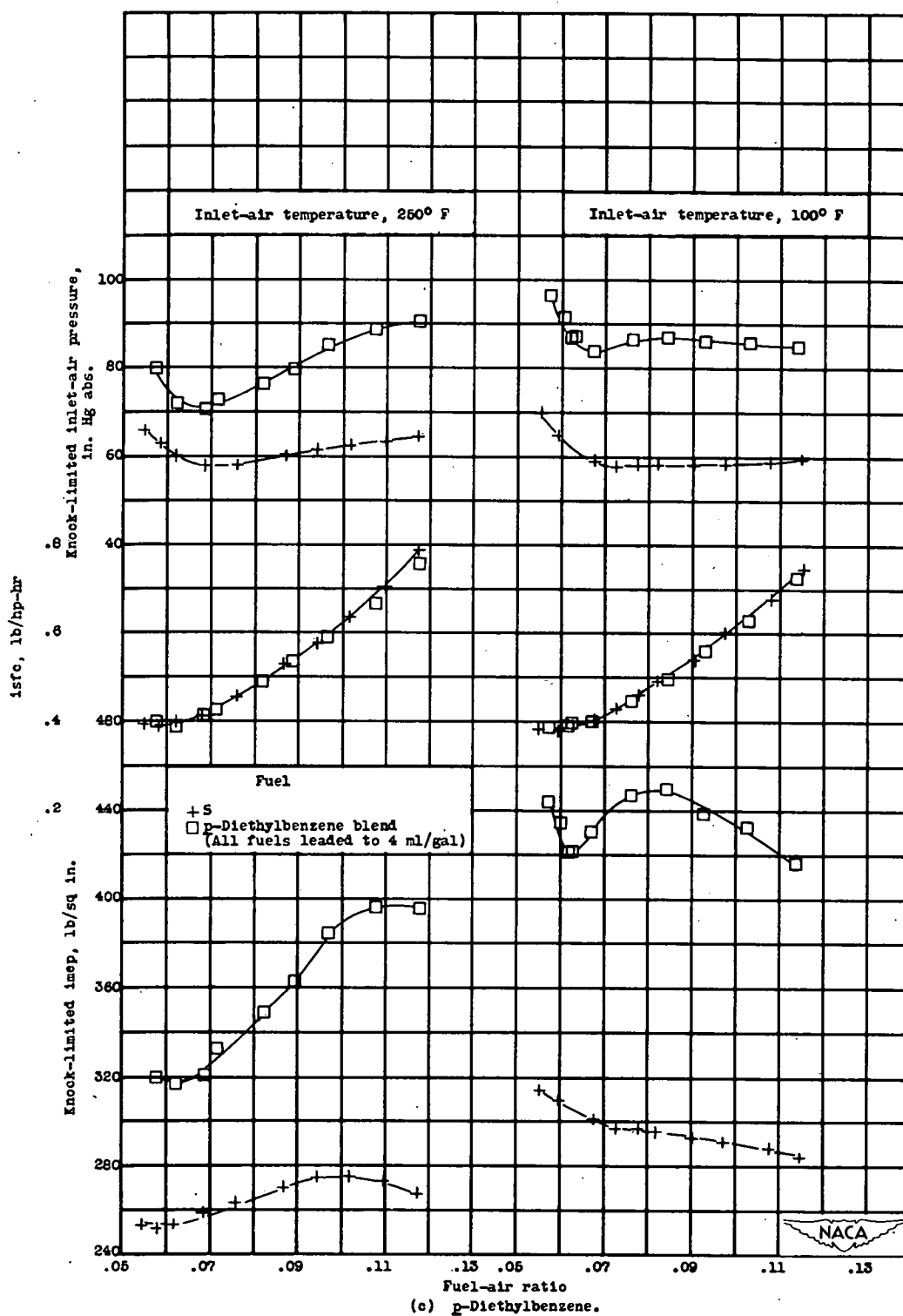
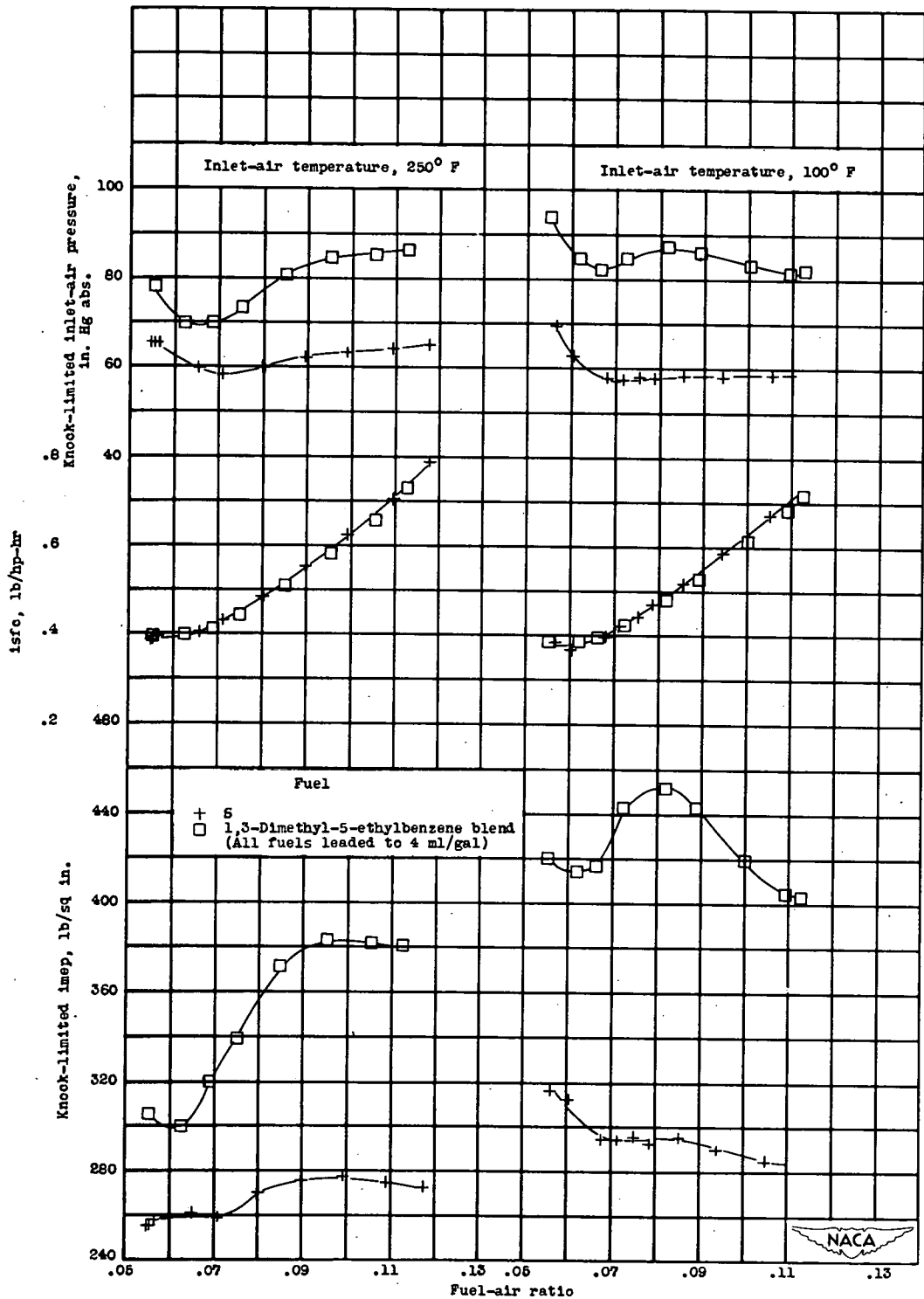


Figure 5. - Continued. Performance of leaded 20-percent aromatic blends with S reference fuel plus 4 ml TEL per gallon in 17.6 engine. Compression ratio, 7.0; engine speed, 1800 rpm; spark advance, 30° B.T.C.; coolant, water at 212° F; incipient knock.



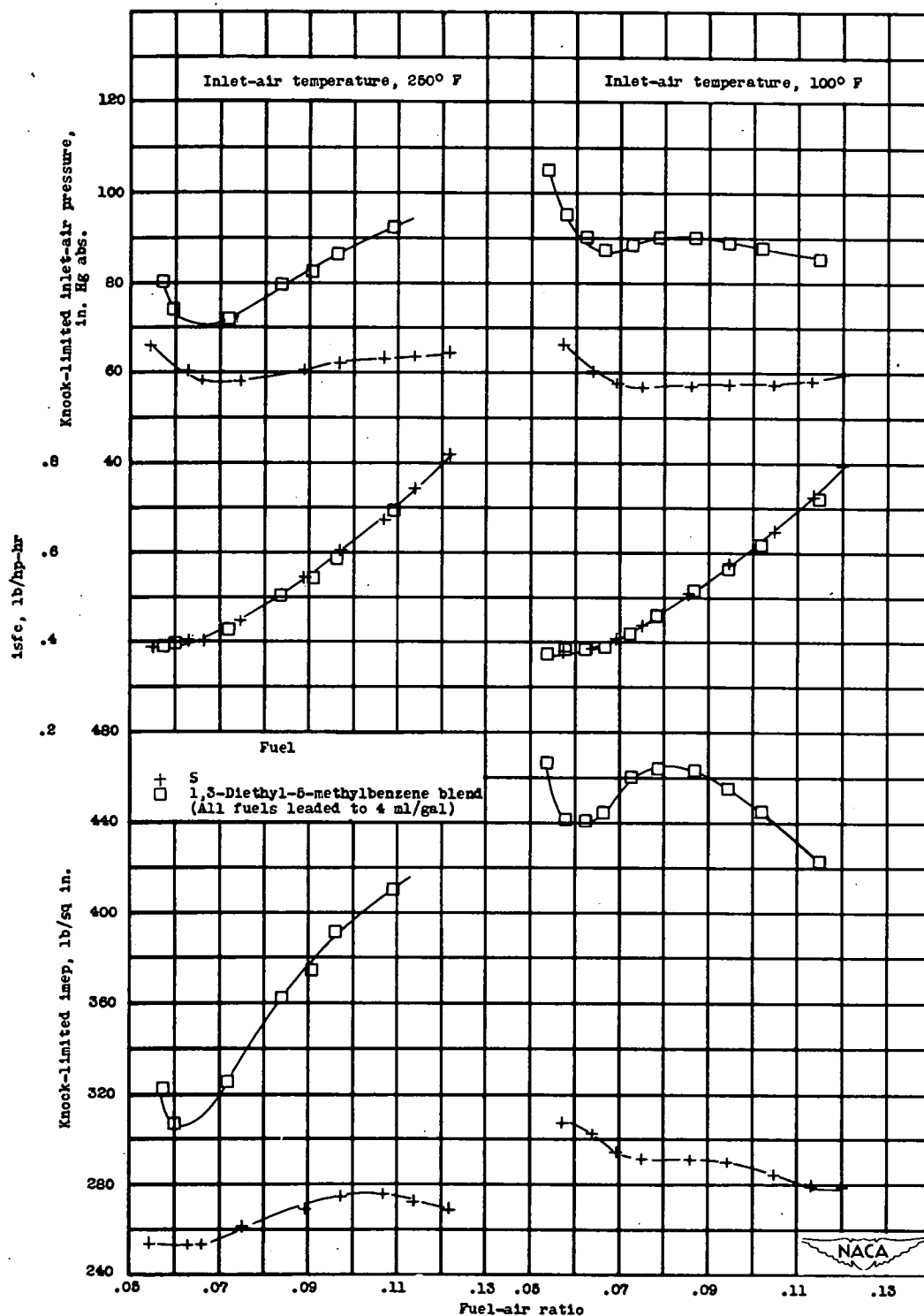


Figure 3. - Continued. Performance of leaded 20-percent aromatic blends with 5 reference fuel plus 4 ml TEL per gallon in 17.6 engine. Compression ratio, 7.0; engine speed, 1800 rpm; spark advance, 30° B.T.C.; coolant, water at 212° F; incipient knock.

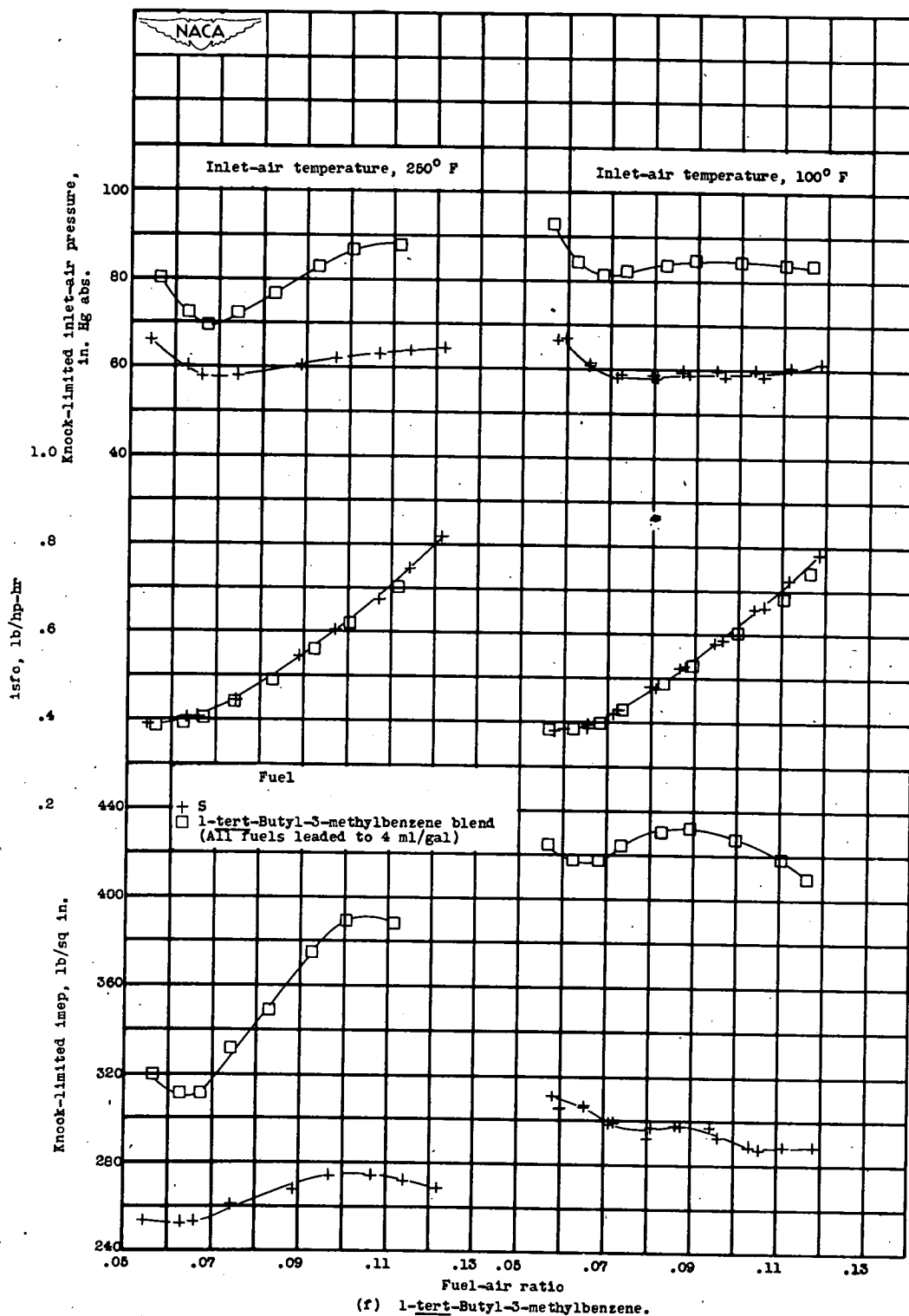


Figure 3. - Continued. Performance of leaded 20-percent aromatic blends with S reference fuel plus 4 ml TEL per gallon in 17.6 engine. Compression ratio, 7.0; engine speed, 1800 rpm; spark advance, 30° B.T.C.; coolant, water at 212° F; incipient knock.

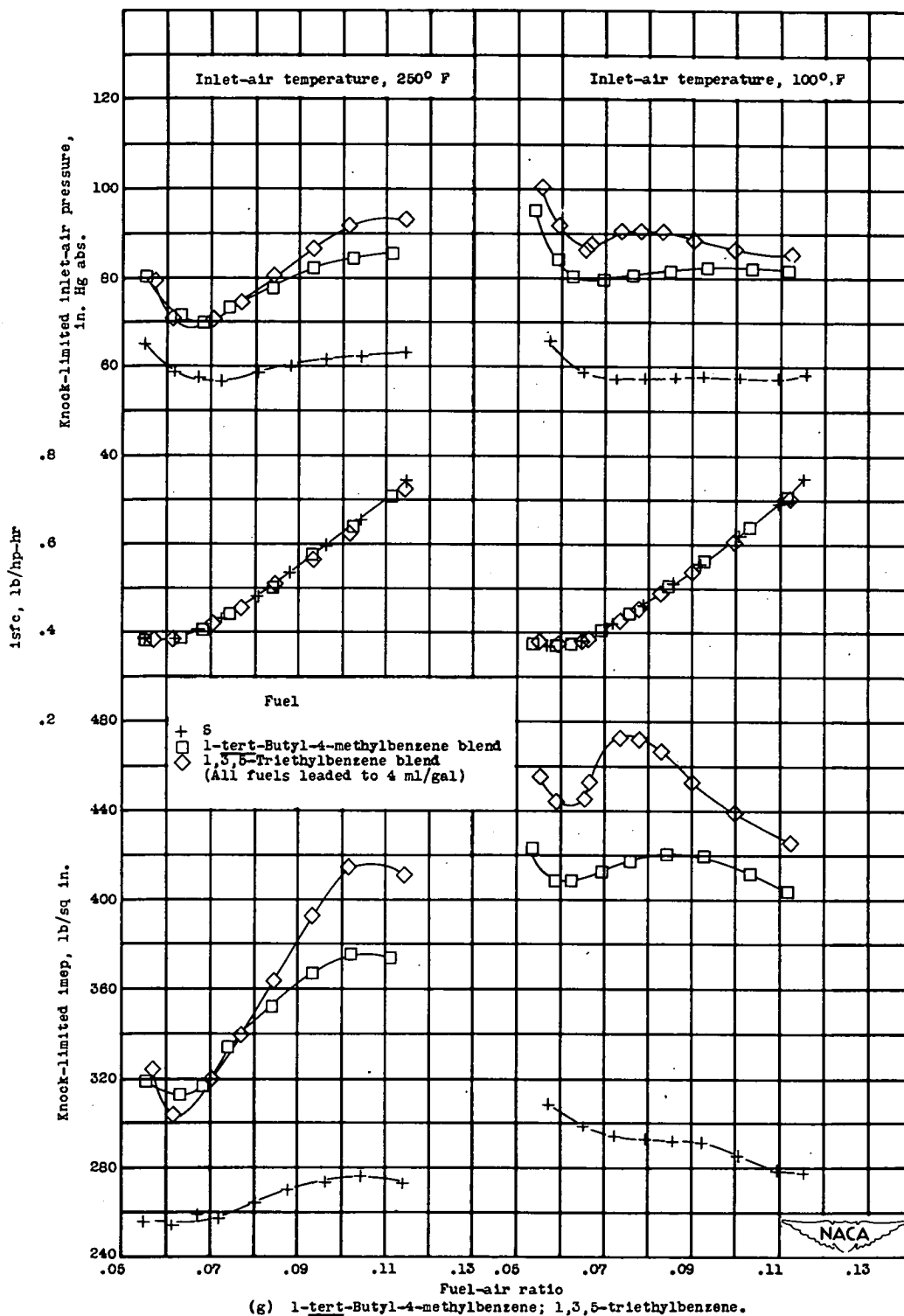
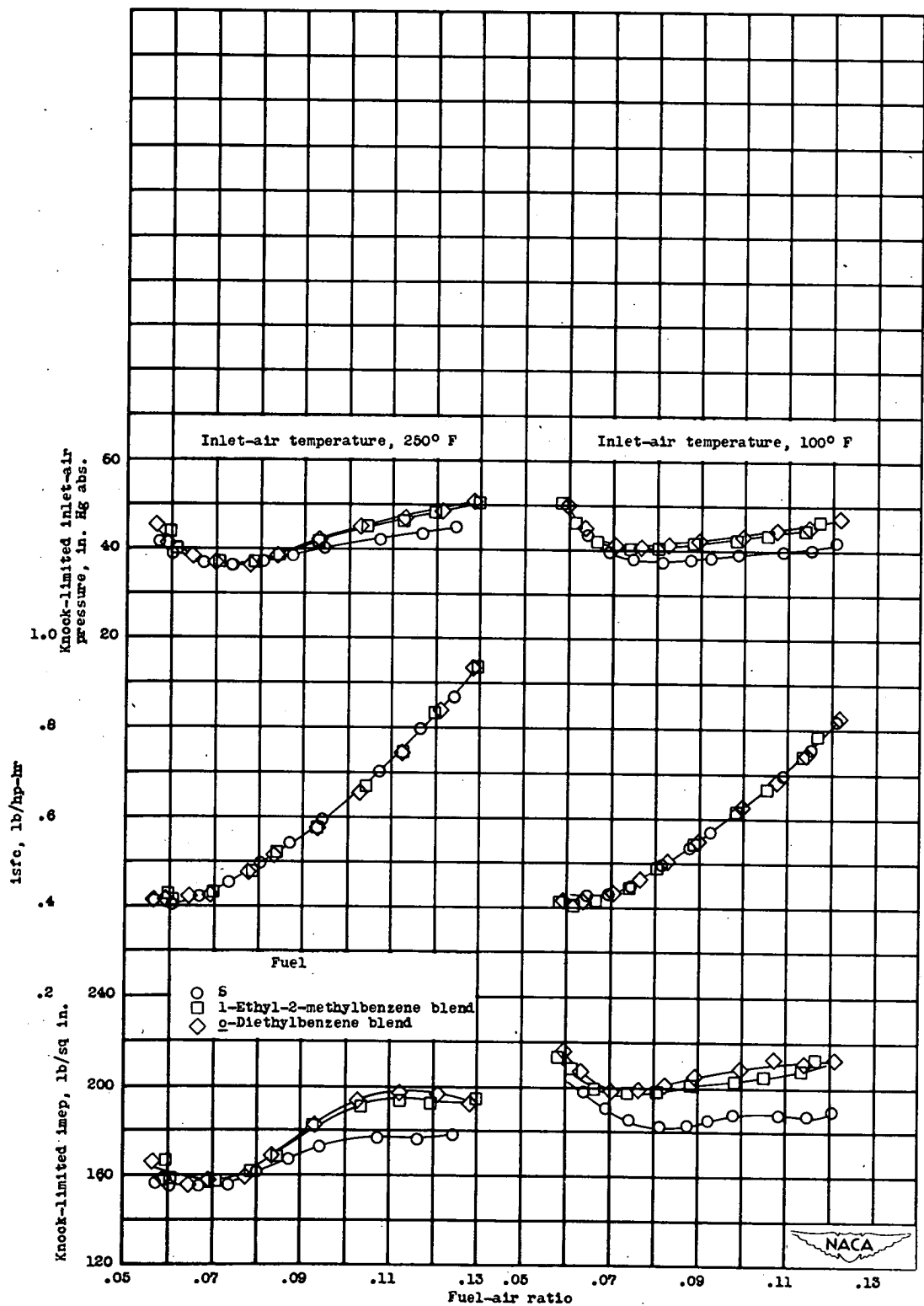


Figure 3. - Concluded. Performance of leaded 20-percent aromatic blends with 8 reference fuel plus 4 ml TEL per gallon in 17.6 engine. Compression ratio, 7.0; engine speed, 1800 rpm; spark advance, 30° B.T.C.; coolant, water at 212° F; incipient knock.



(a) 1-Ethyl-2-methylbenzene; o-diethylbenzene.

Figure 4. - Performance of unleaded 20-percent aromatic blends with S reference fuel in 17.6 engine. Compression ratio, 7.0; engine speed, 1800 rpm; spark advance, 30° B.T.C.; coolant, water at 212° F; incipient knock.

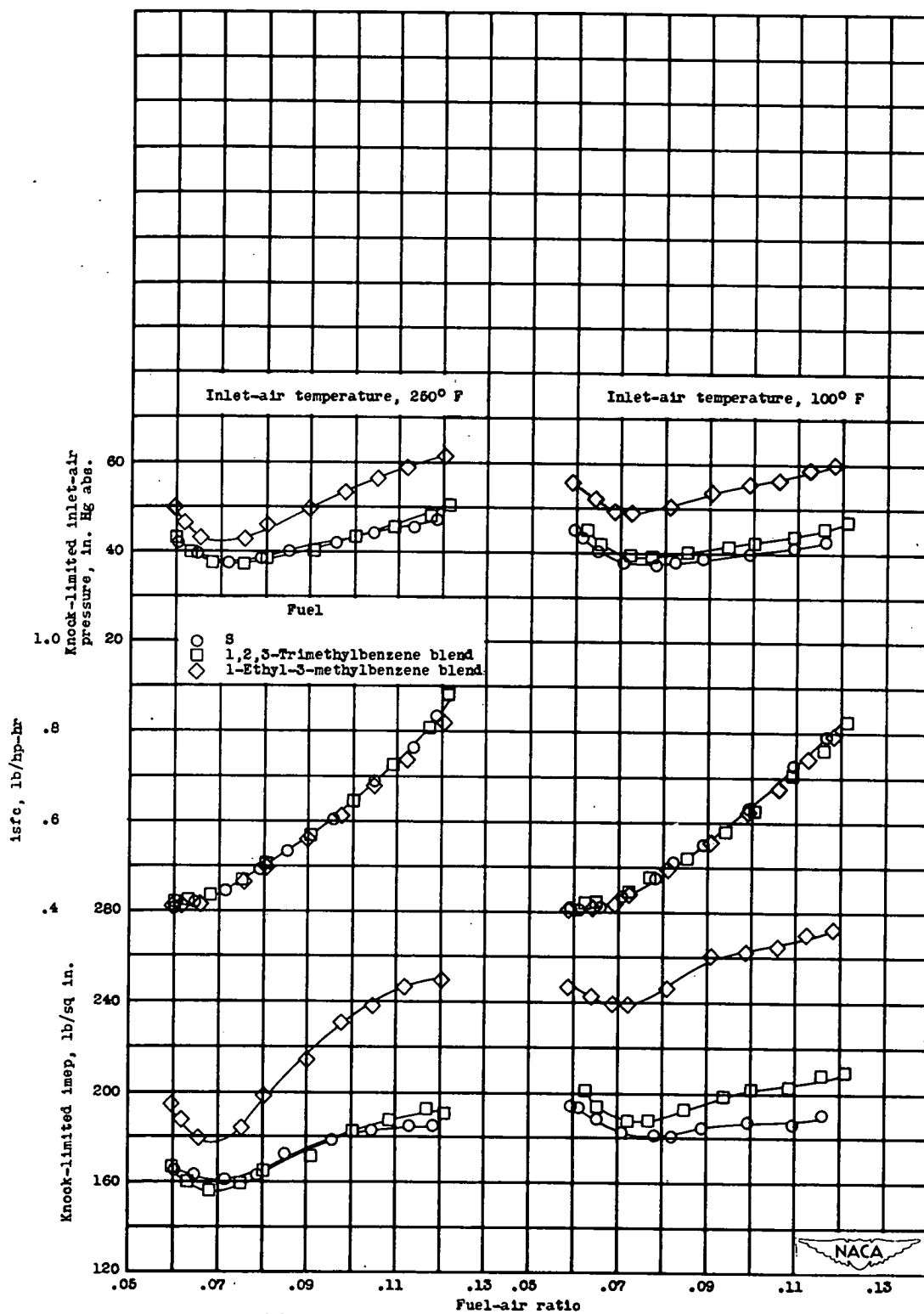
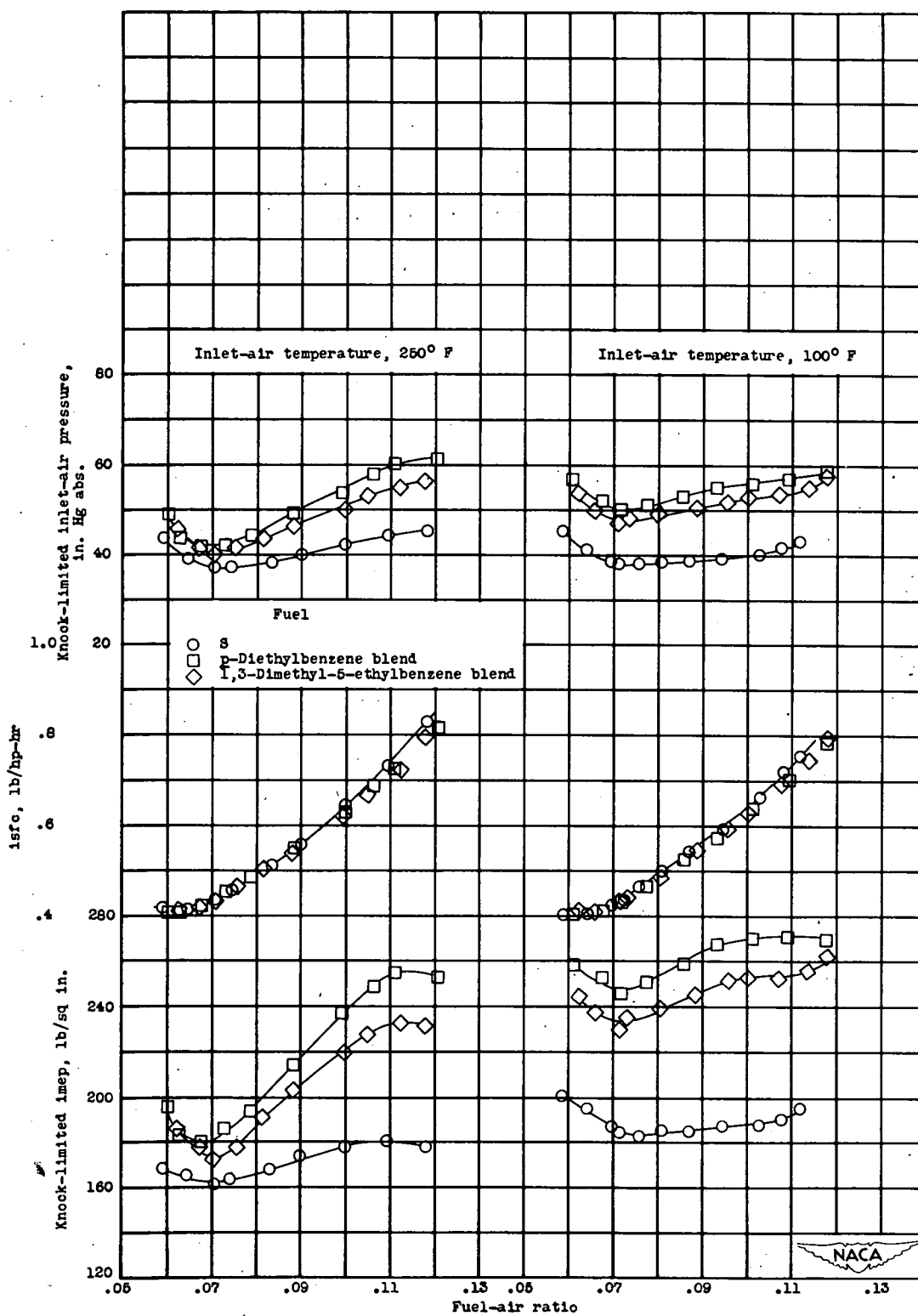


Figure 4. - Continued. Performance of unleaded 20-percent aromatic blends with 8 reference fuel in 17.6 engine. Compression ratio, 7.0; engine speed, 1800 rpm; spark advance, 30° B.T.C.; coolant, water at 212° F; incipient knock.



(c) p-Diethylbenzene; 1,3-dimethyl-5-ethylbenzene.

Figure 4. - Continued. Performance of unleaded 20-percent aromatic blends with S reference fuel in 17.6 engine. Compression ratio, 7.0; engine speed, 1800 rpm; spark advance, 30° B.T.C.; coolant, water at 212° F; incipient knock.

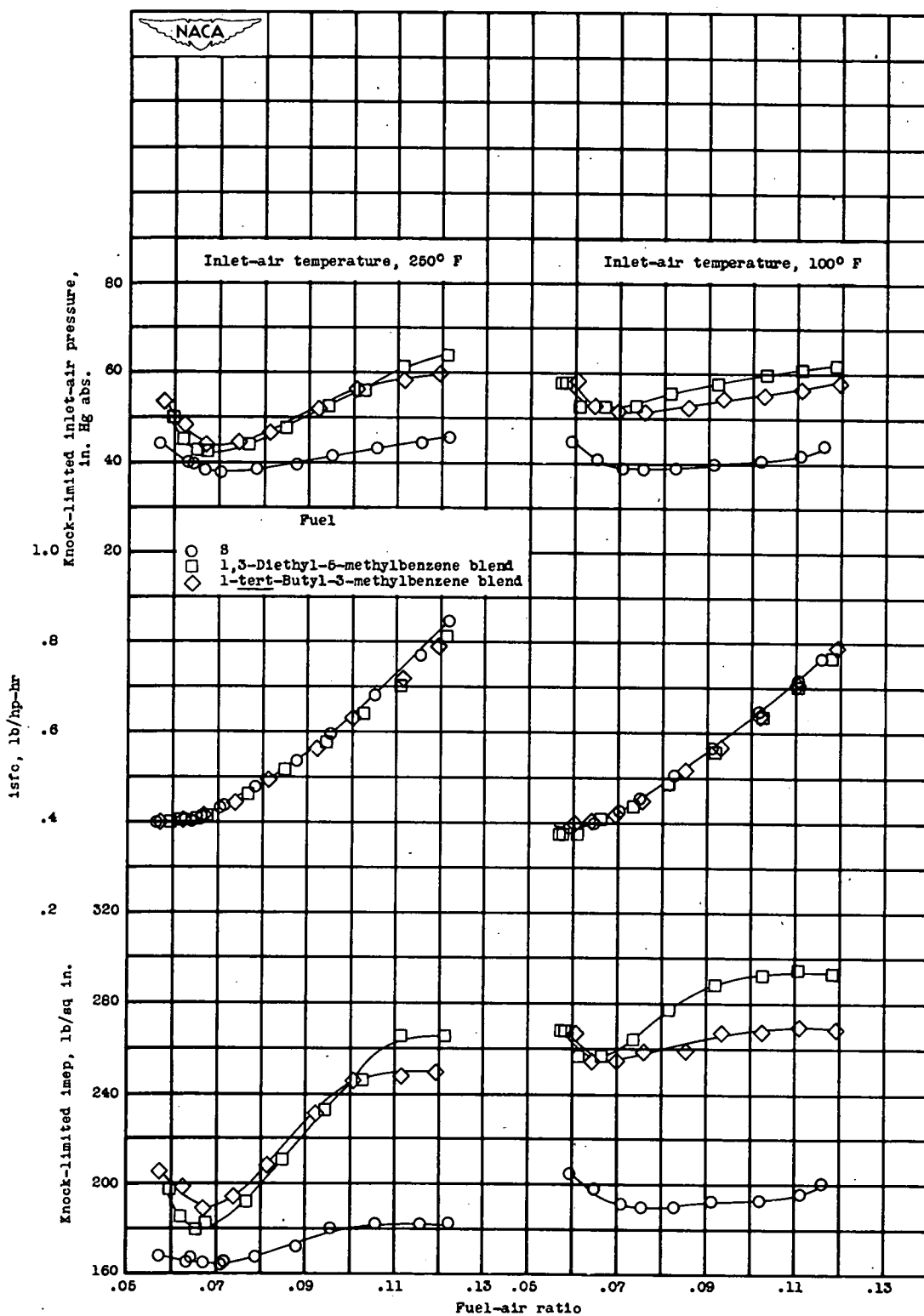
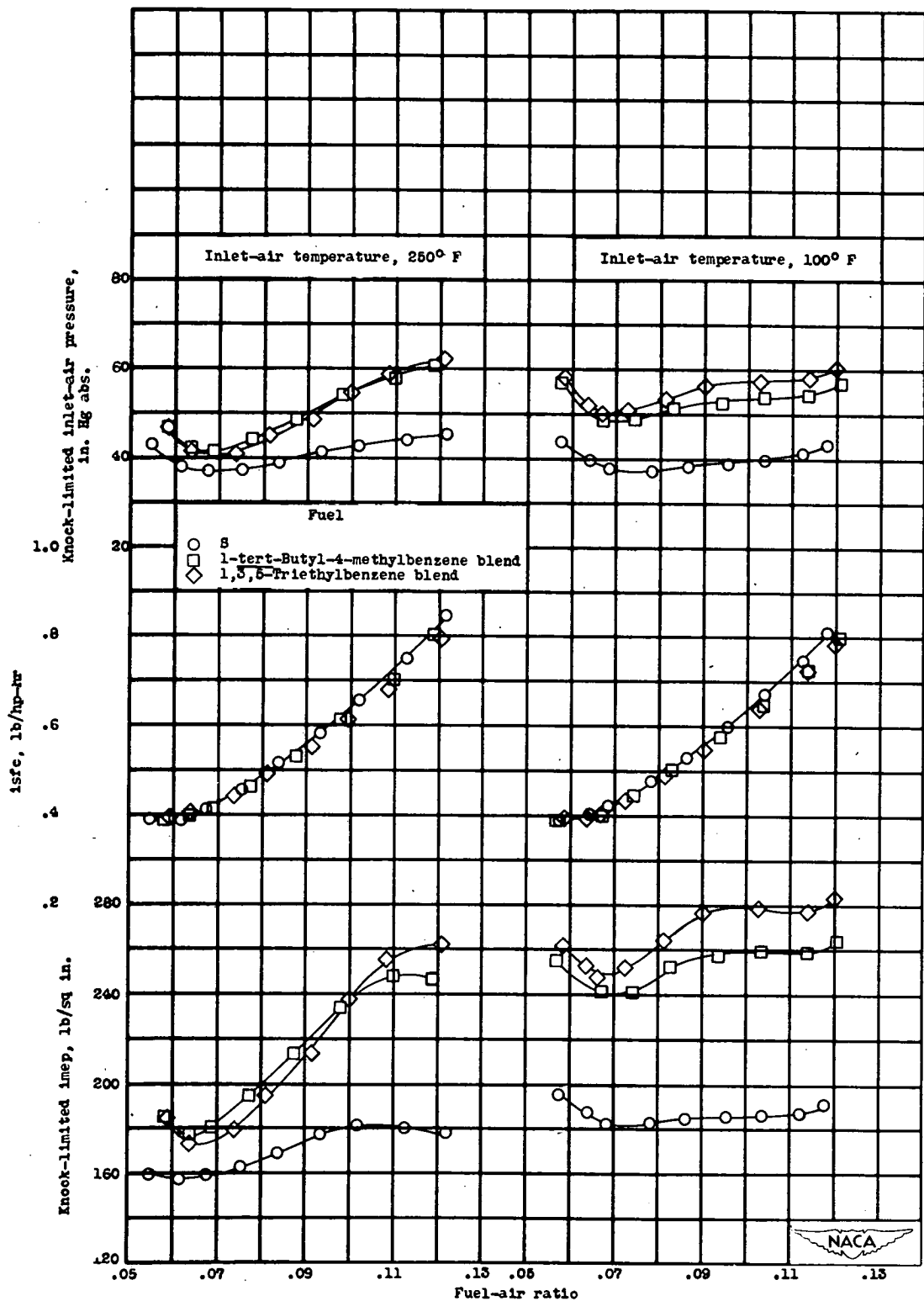


Figure 4. - Continued. Performance of unleaded 20-percent aromatic blends with 8 reference fuel in 17.6 engine. Compression ratio, 7.0; engine speed, 1800 rpm; spark advance, 30° B.T.C.; coolant, water at 212° F; incipient knock.



(e) 1-tert-Butyl-4-methylbenzene; 1,3,5-triethylbenzene.

Figure 4. - Concluded. Performance of unleaded 20-percent aromatic blends with 8 reference fuel in 17.6 engine. Compression ratio, 7.0; engine speed, 1800 rpm; spark advance, 30° B.T.C.; coolant, water, at 212° F; incipient knock.

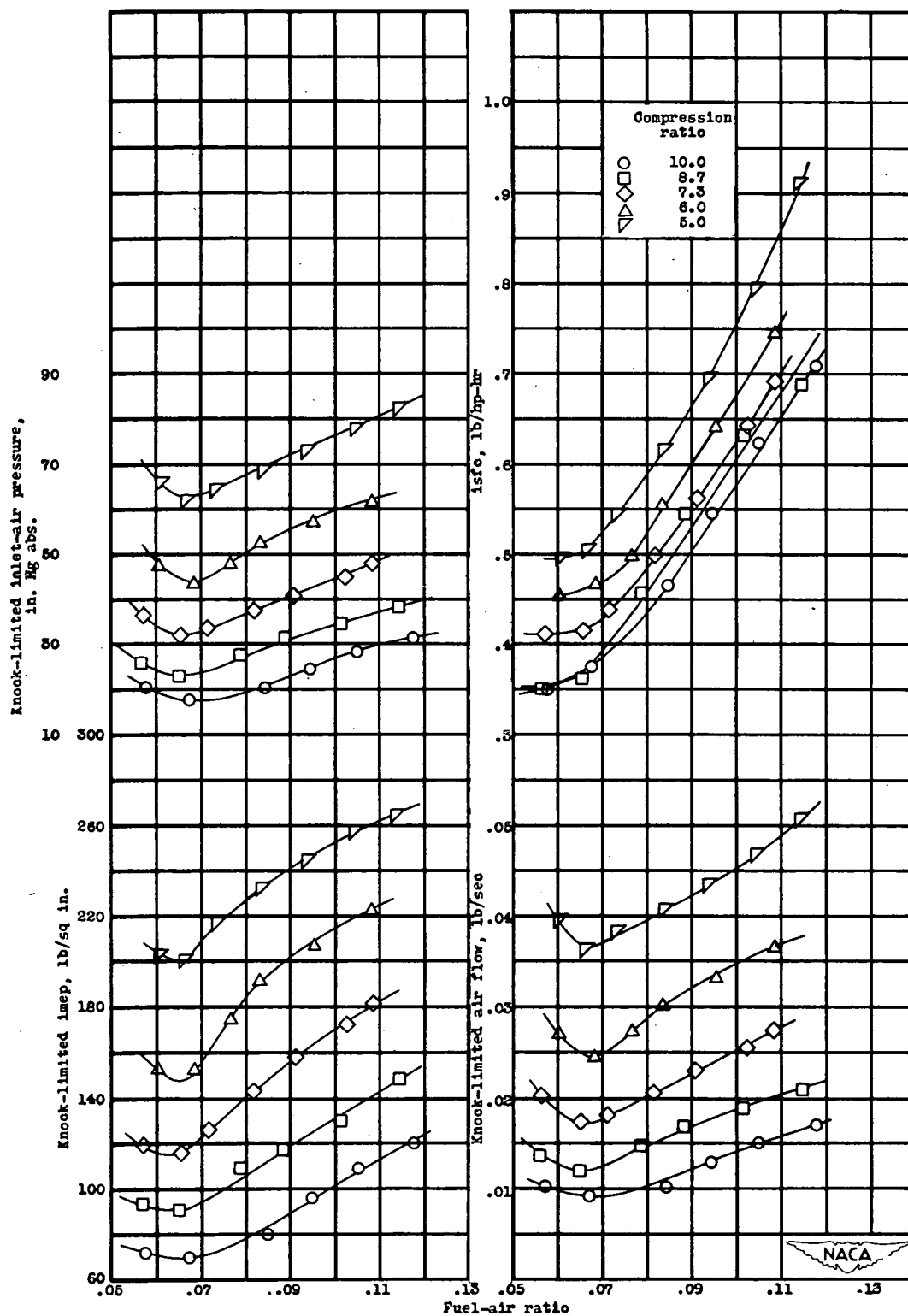


Figure 5. - Performance of leaded 26-percent aromatic blends with base fuel consisting of 87.5 percent 5 reference fuel and 12.5 percent n-heptane plus 4 ml TEL per gallon in modified CFR engine. Engine speed, 1800 rpm; spark advance, 20° B.T.O.; coolant, water at 250° F; inlet-air temperature, 250° F; incipient knock.

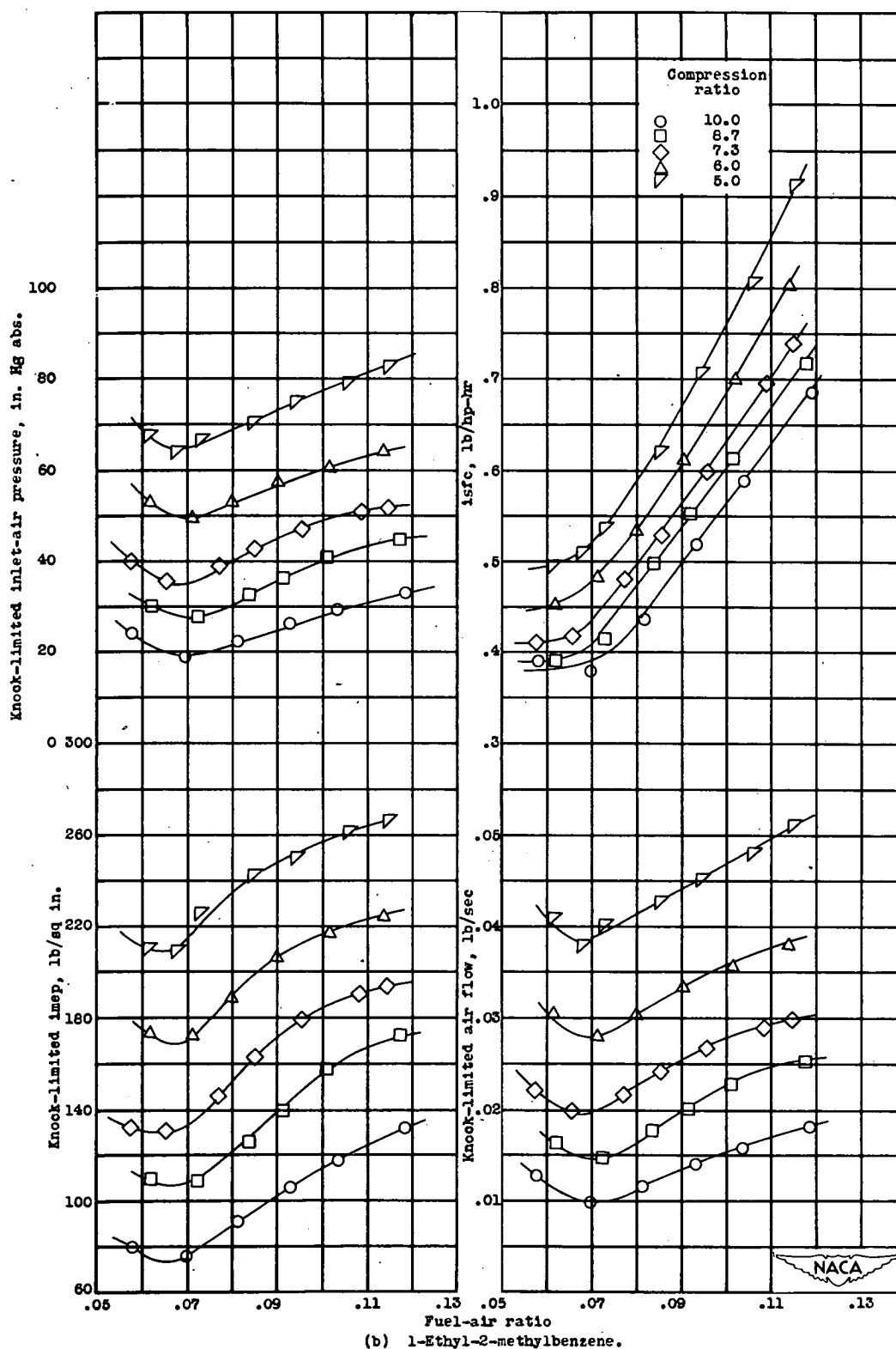


Figure 6. - Continued. Performance of leaded 25-percent aromatic blends with base fuel consisting of 87.5 percent S reference fuel and 12.5 percent n-heptane plus 4 ml TEL per gallon in modified CFR engine. Engine speed, 1800 rpm; spark advance, -20° B.T.C.; coolant, water at 250° F; inlet-air temperature, 250° F; incipient knock.

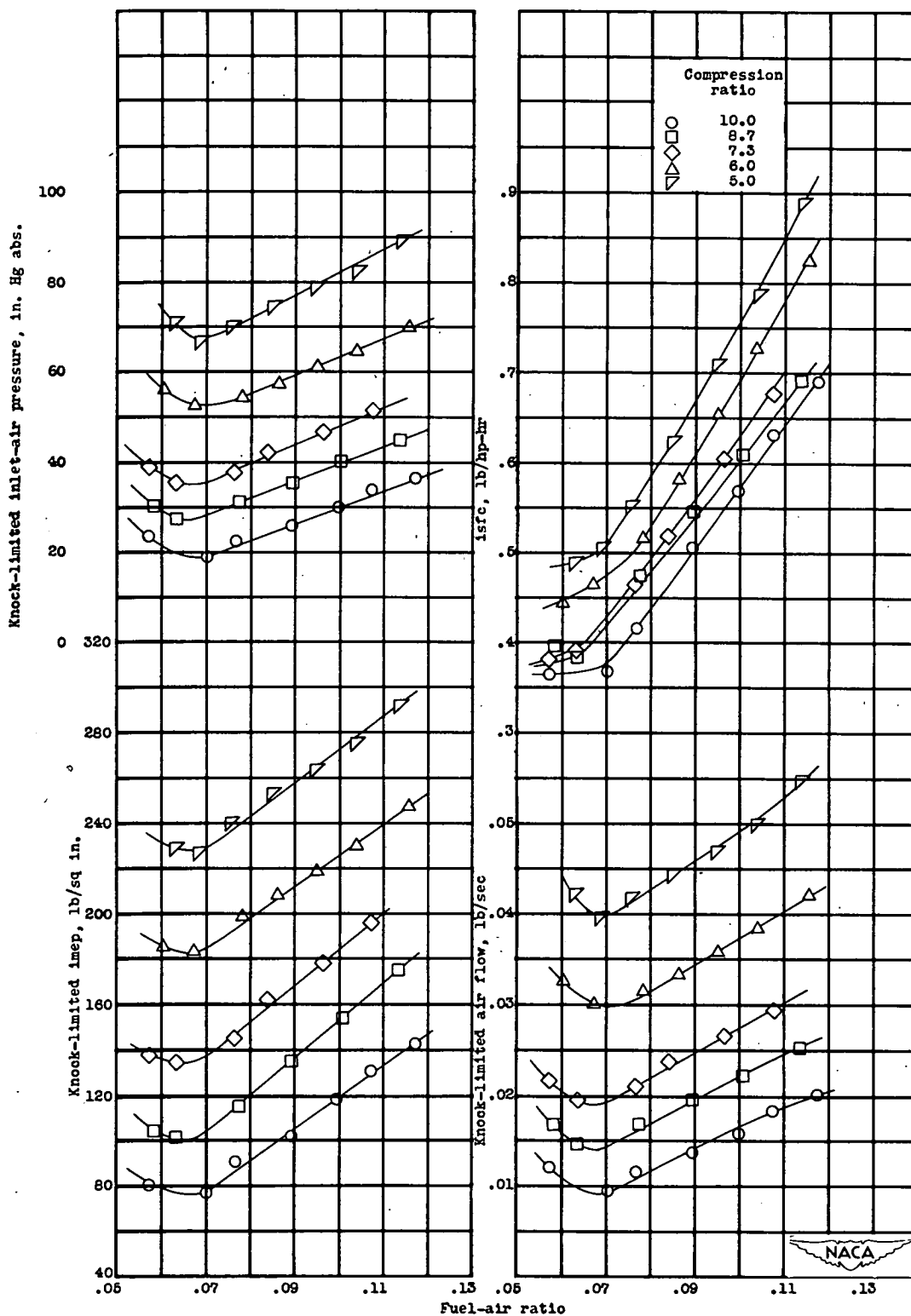


Figure 5. - Continued. Performance of leaded 25-percent aromatic blends with base fuel consisting of 87.5 percent 5 reference fuel and 12.5 percent n-heptane plus 4 ml TEL per gallon in modified CFR engine. Engine speed, 1800 rpm; spark advance, 20° B.T.C.; coolant, water at 250° F; inlet-air temperature, 250° F; incipient knock.

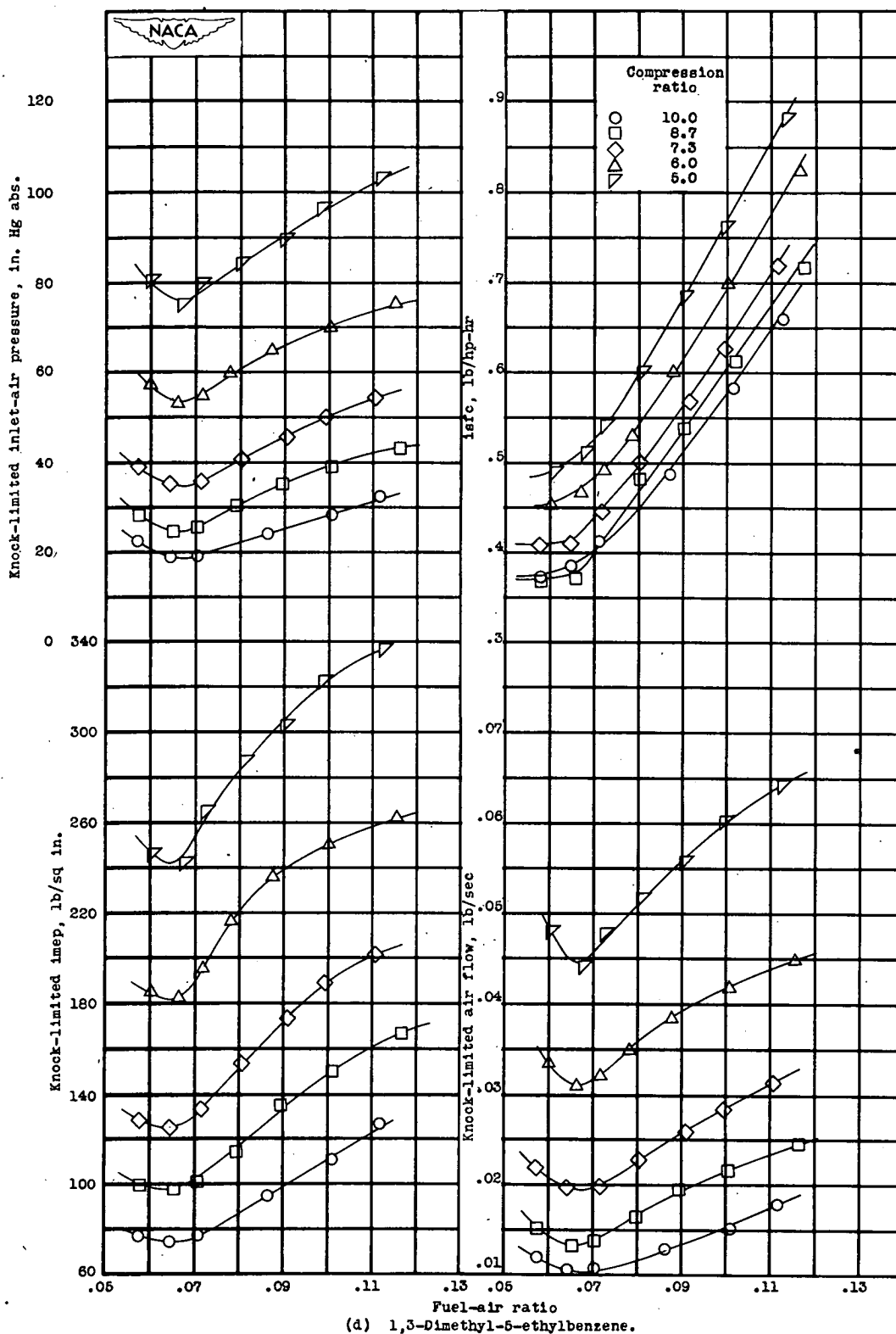
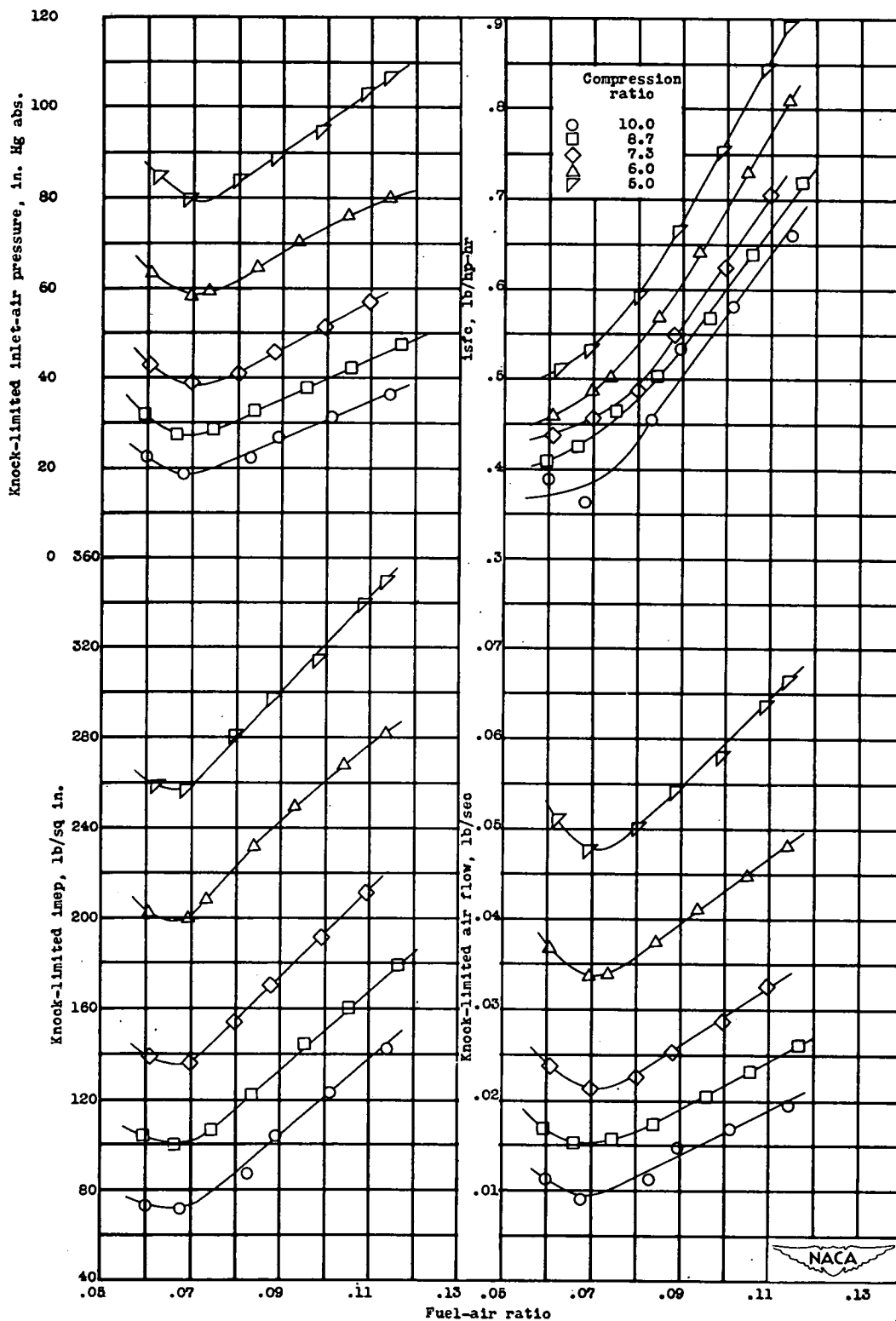


Figure 5. - Continued. Performance of leaded 25-percent aromatic blends with base fuel consisting of 87.5 percent 5 reference fuel and 12.5 percent n-heptane plus 4 ml TEL per gallon in modified CFR engine. Engine speed, 1800 rpm; spark advance, 20° B.T.C.; coolant, water at 250° F; inlet-air temperature, 250° F; incipient knock.



(e) 1-Ethyl-3-methylbenzene.

Figure 5. - Continued. Performance of leaded 25-percent aromatic blends with base fuel consisting of 87.5 percent 5 reference fuel and 12.5 percent n-heptane plus 4 ml TEL per gallon in modified CFR engine. Engine speed, 1800 rpm; spark advance, 20° B.T.C.; coolant, water at 250° F; inlet-air temperature, 250° F; incipient knock.

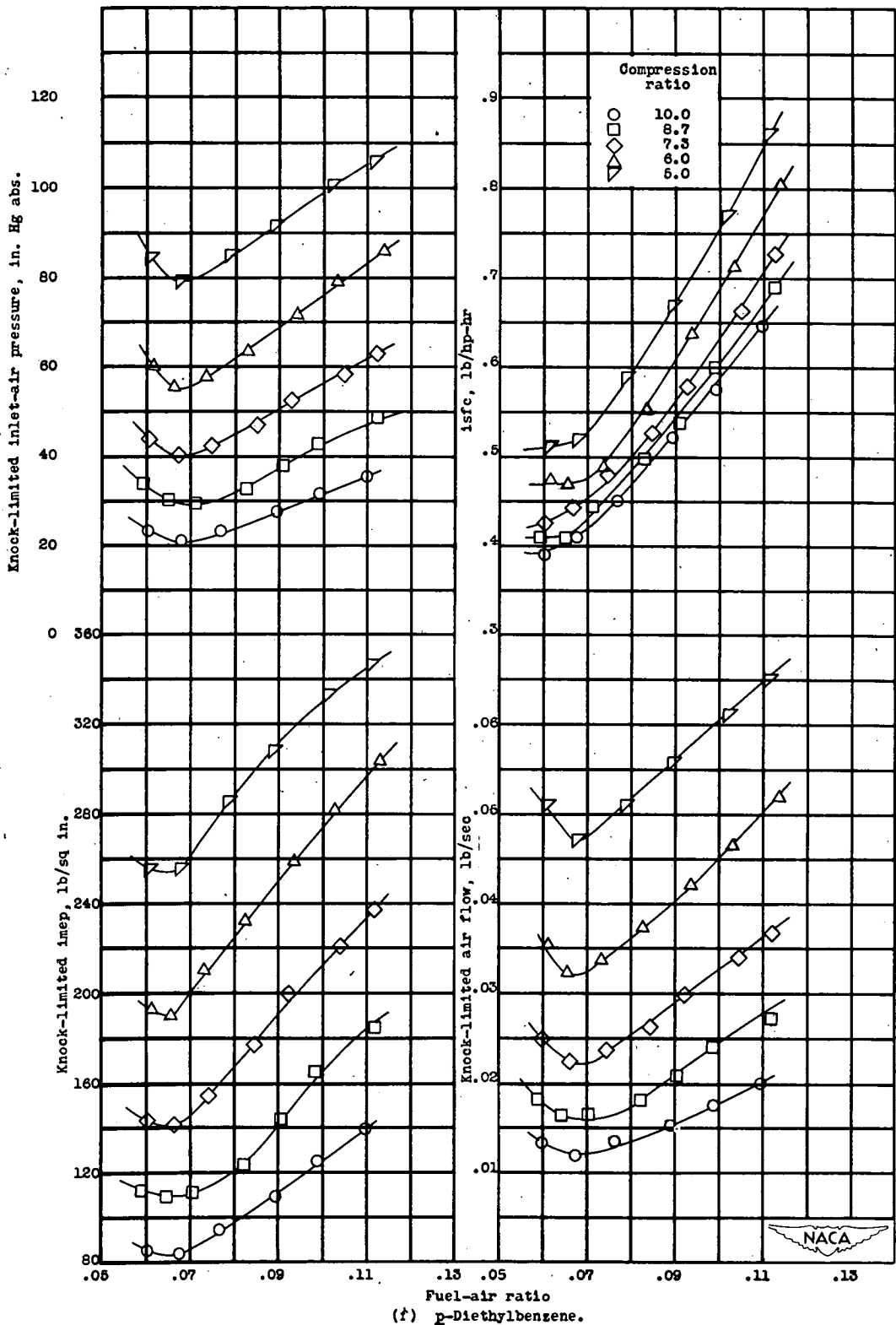


Figure 5. - Continued. Performance of leaded 25-percent aromatic blends with base fuel consisting of 87.5 percent 3 reference fuel and 12.5 percent *n*-heptane plus 4 ml TEL per gallon in modified CFR engine. Engine speed, 1800 rpm; spark advance, 20° B.T.C.; coolant, water at 250° F; inlet-air temperature, 250° F; incipient knock.

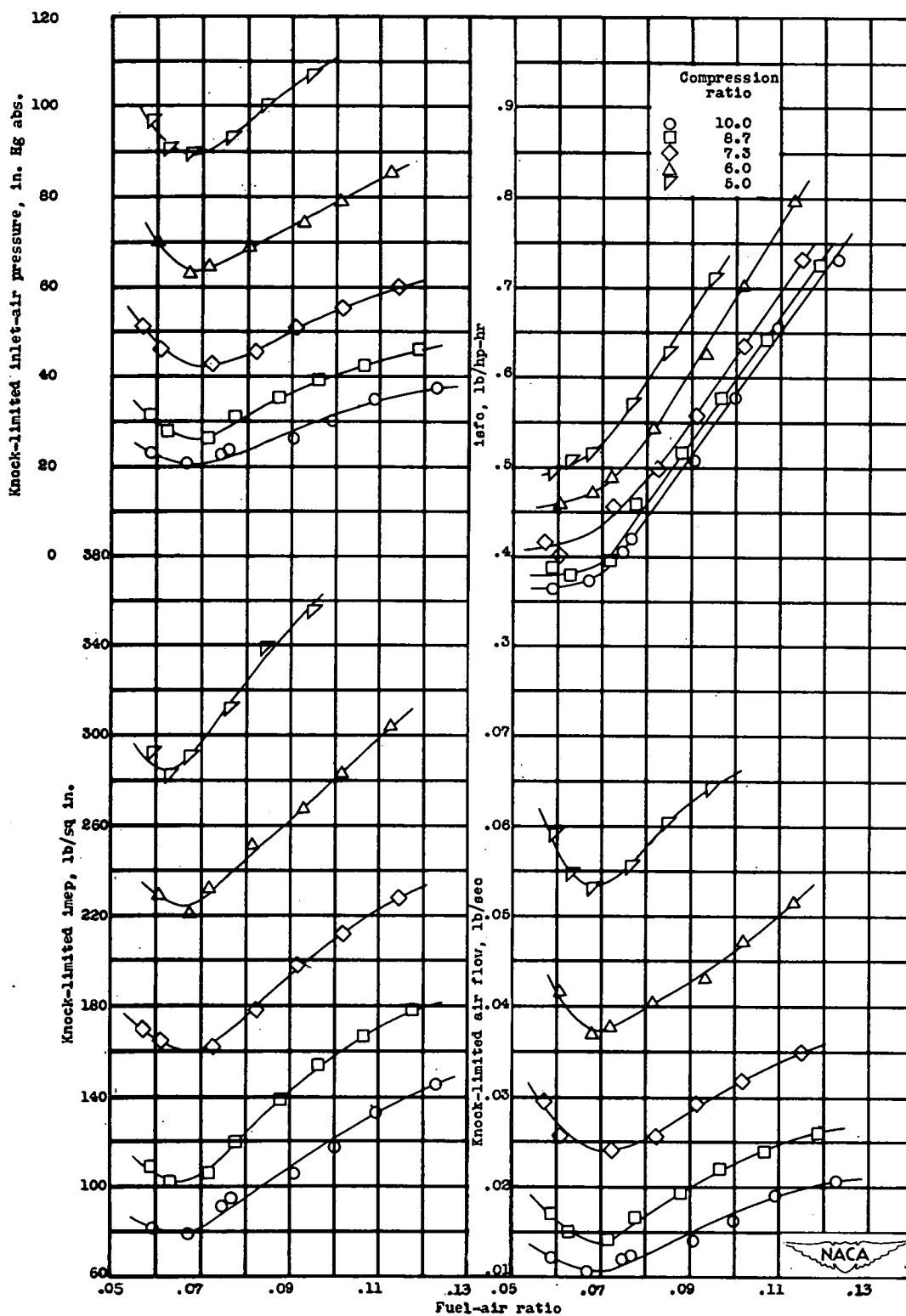


Figure 5. - Continued. Performance of leaded 25-percent aromatic blends with base fuel consisting of 87.5 percent 5 reference fuel and 12.5 percent *n*-heptane plus 4 ml TEL per gallon in modified CFR engine. Engine speed, 1800 rpm; spark advance, 20° B.T.C.; coolant, water at 260° F; inlet-air temperature, 280° F; incipient knock.

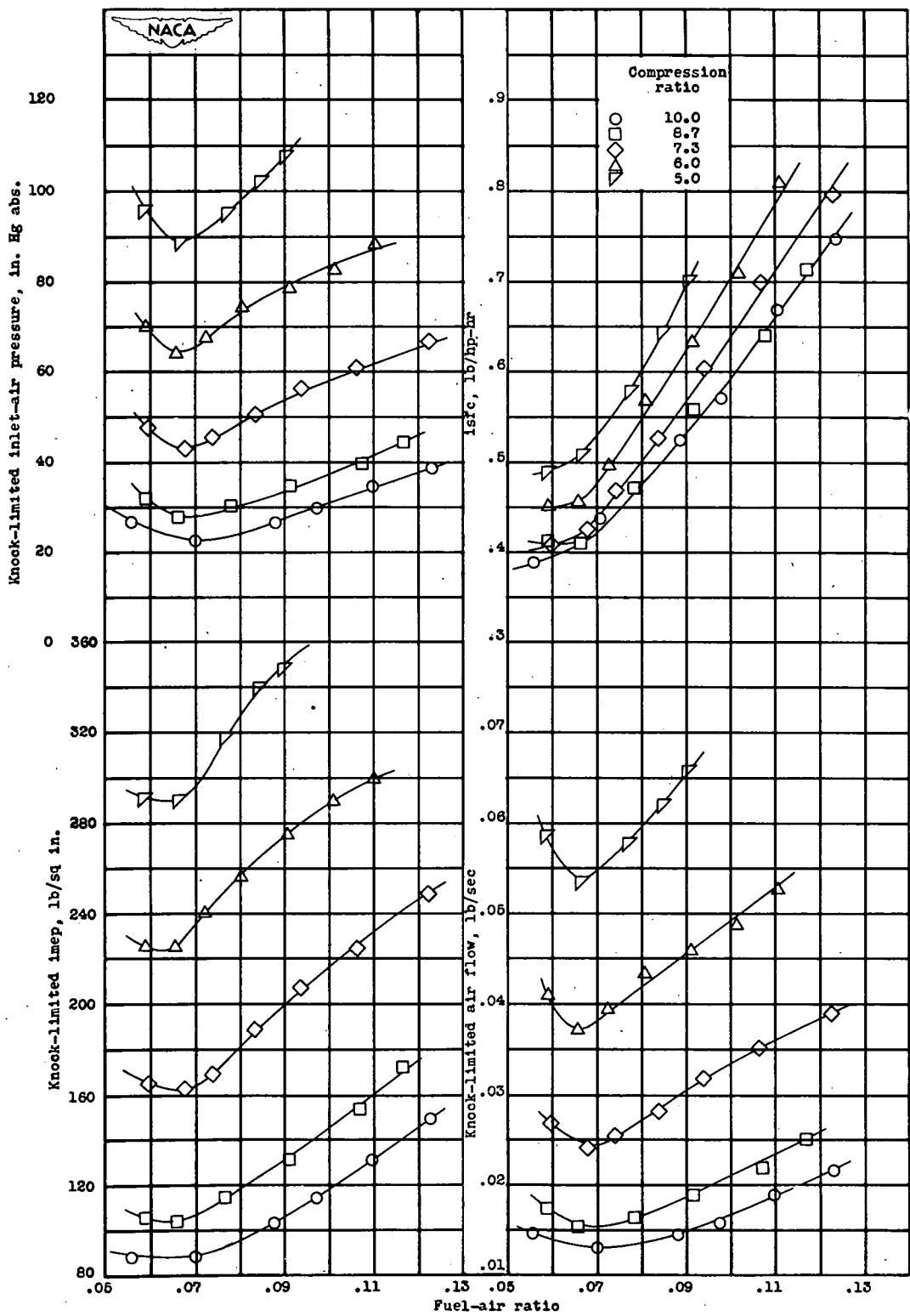
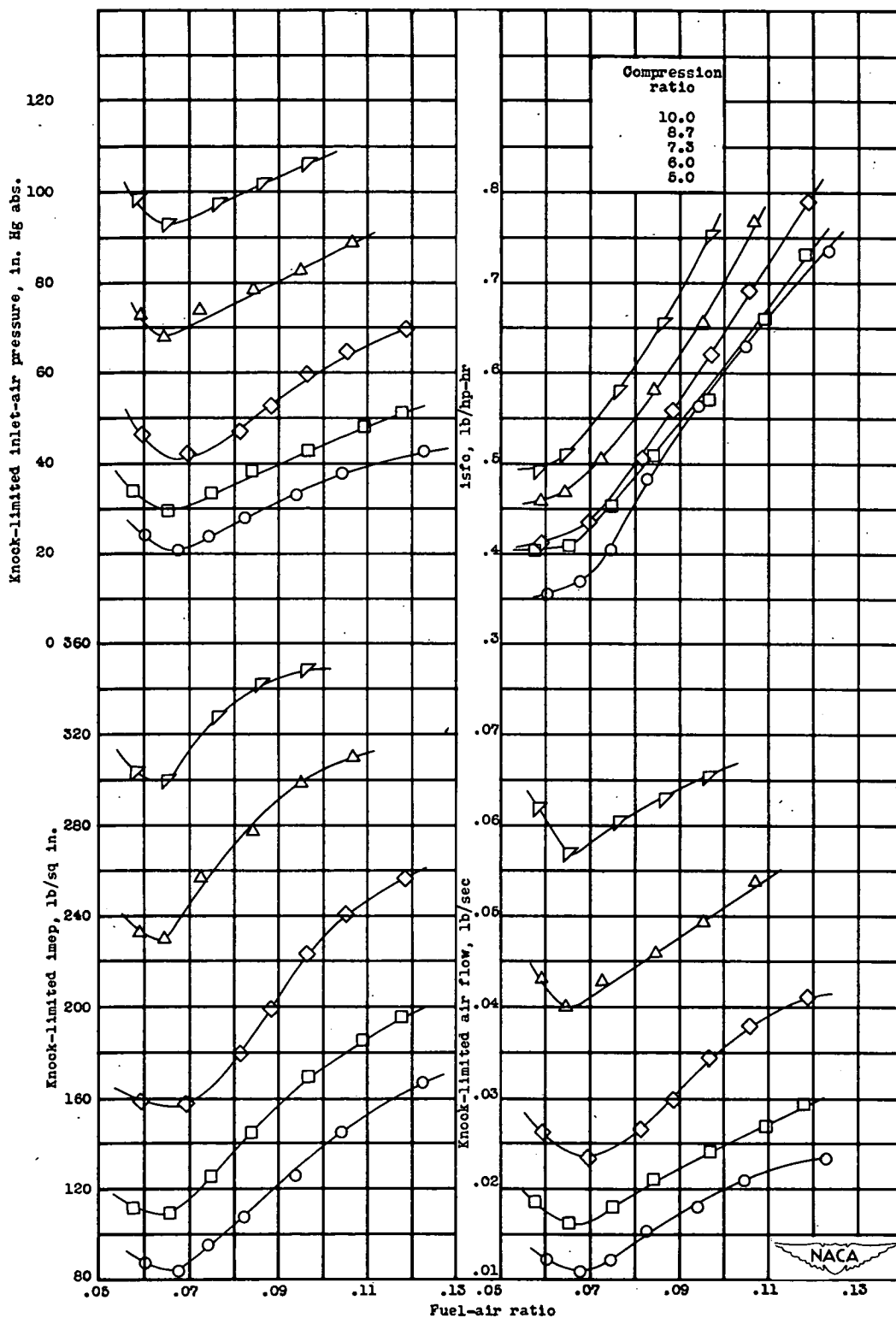


Figure 5. - Continued. Performance of leaded 25-percent aromatic blends with base fuel consisting of 87.5 percent 5 reference fuel and 12.5 percent *n*-heptane plus 4 ml TEL per gallon in modified CFR engine. Engine speed, 1800 rpm; spark advance, 20° B.T.C.; coolant, water at 250° F; inlet-air temperature, 260° F; incipient knock.



(1) 1-tert-Butyl-3-methylbenzene.

Figure 5. - Continued. Performance of leaded 25-percent aromatic blends with base fuel consisting of 87.5 percent B reference fuel and 12.5 percent n-heptane plus 4 ml TEL per gallon in modified CFR engine. Engine speed, 1800 rpm; spark advance, 20° B.T.C.; coolant, water at 250° F; inlet-air temperature, 250° F; incipient knock.

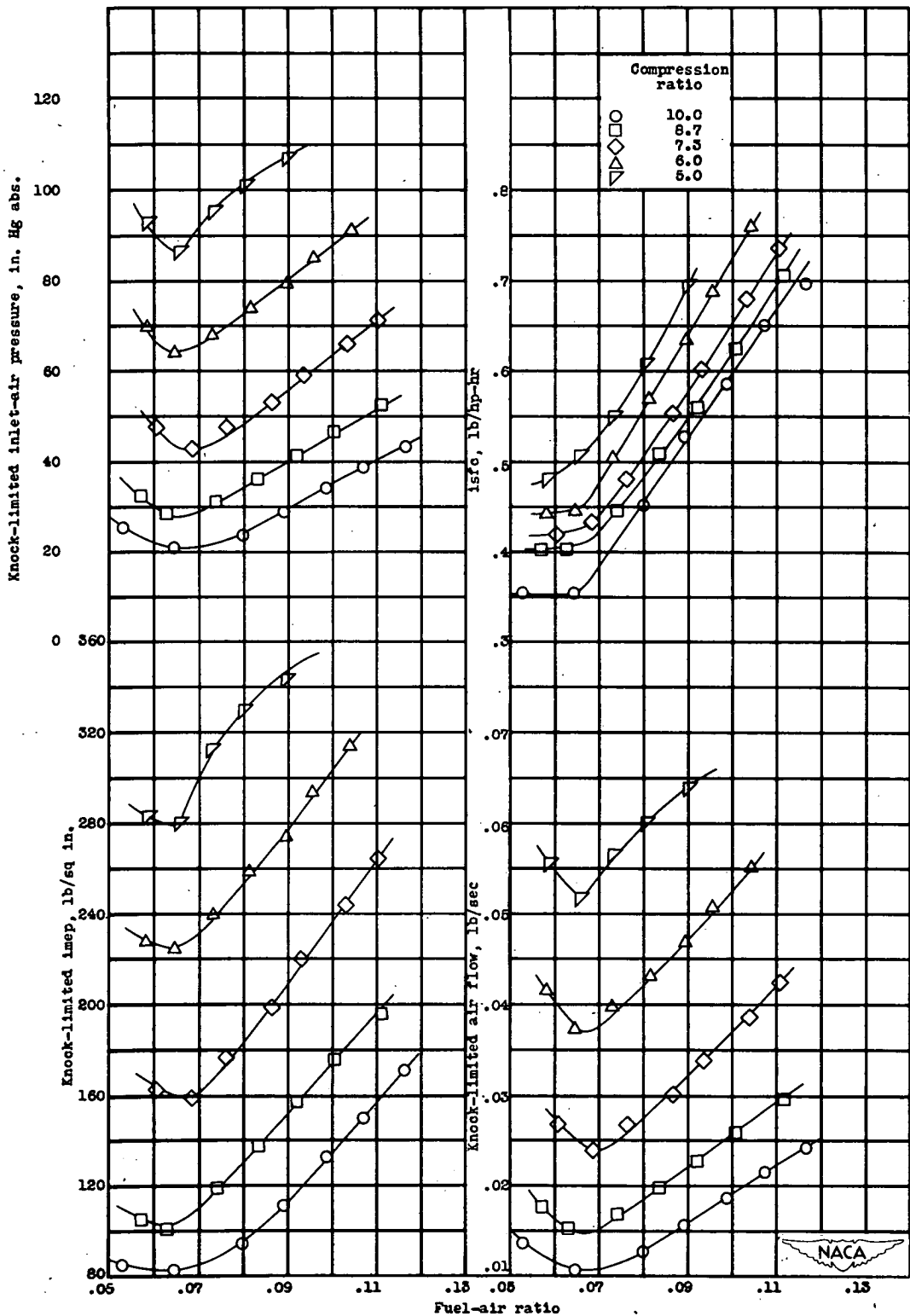


Figure 6. - Continued. Performance of leaded 25-percent aromatic blends with base fuel consisting of 87.5 percent 5 reference fuel and 12.5 percent *n*-heptane plus 4 ml TEL per gallon in modified CFR engine. Engine speed, 1800 rpm; spark advance, 20° B.T.O.; coolant, water at 280° F; inlet-air temperature, 260° F; incipient knock.

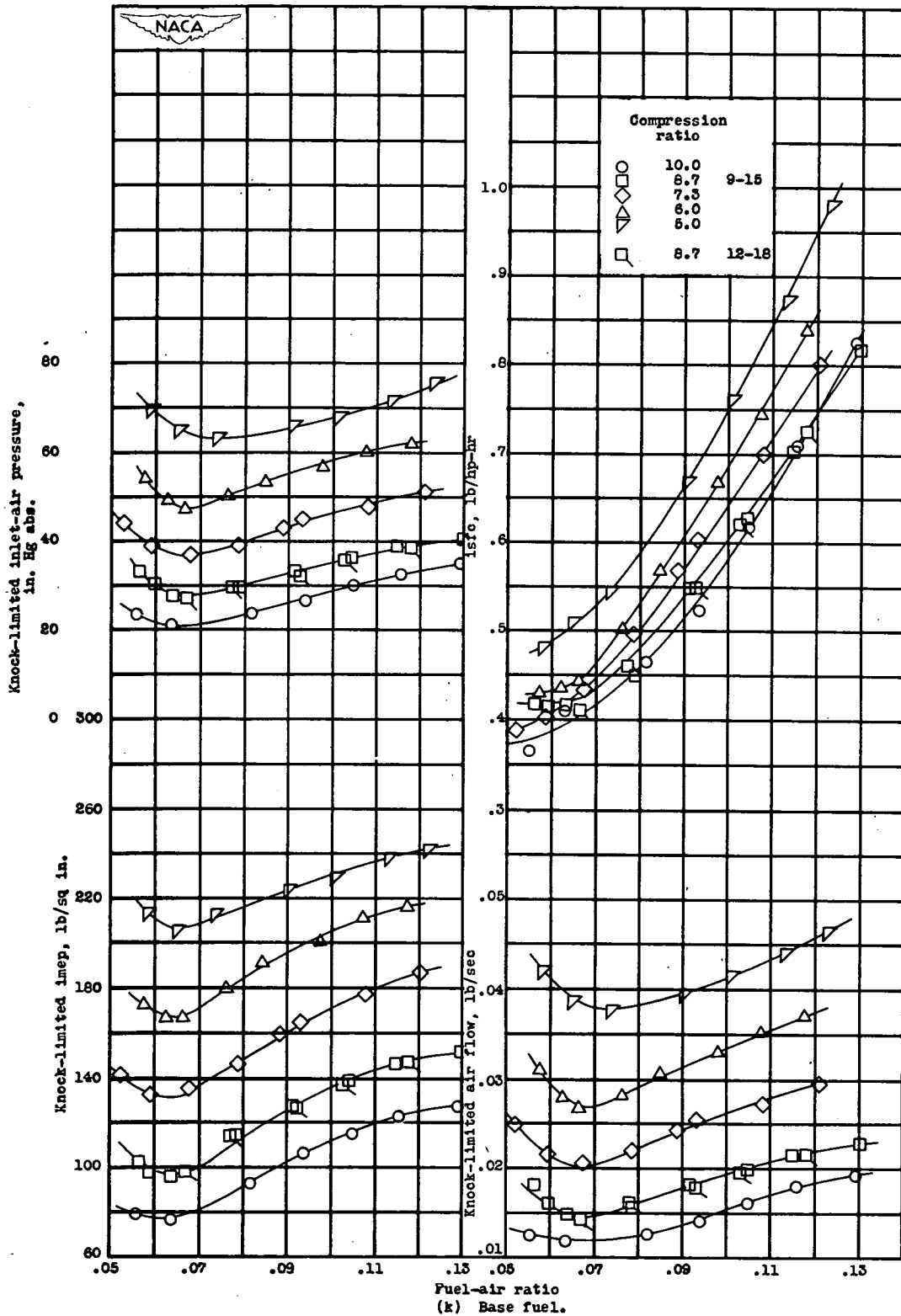
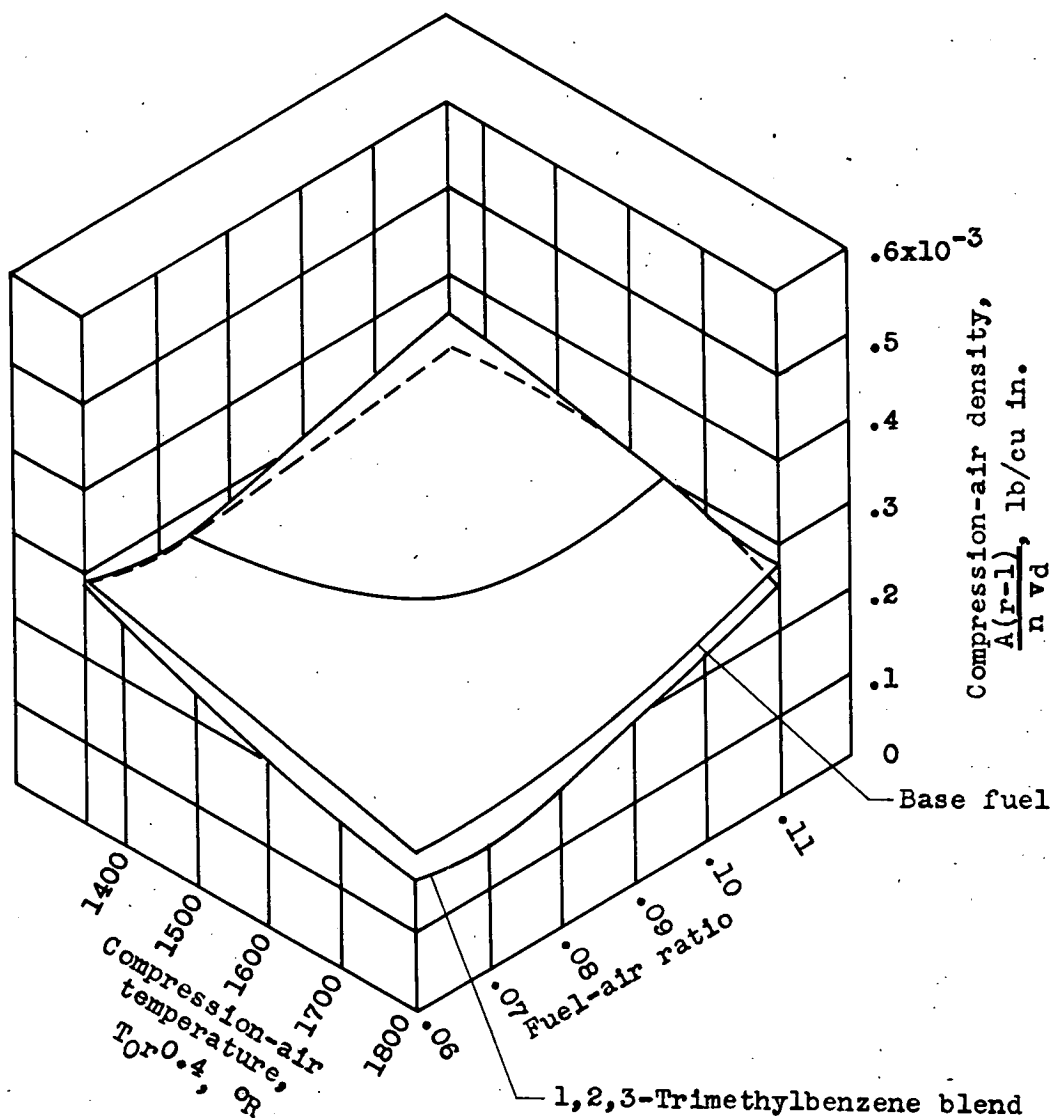


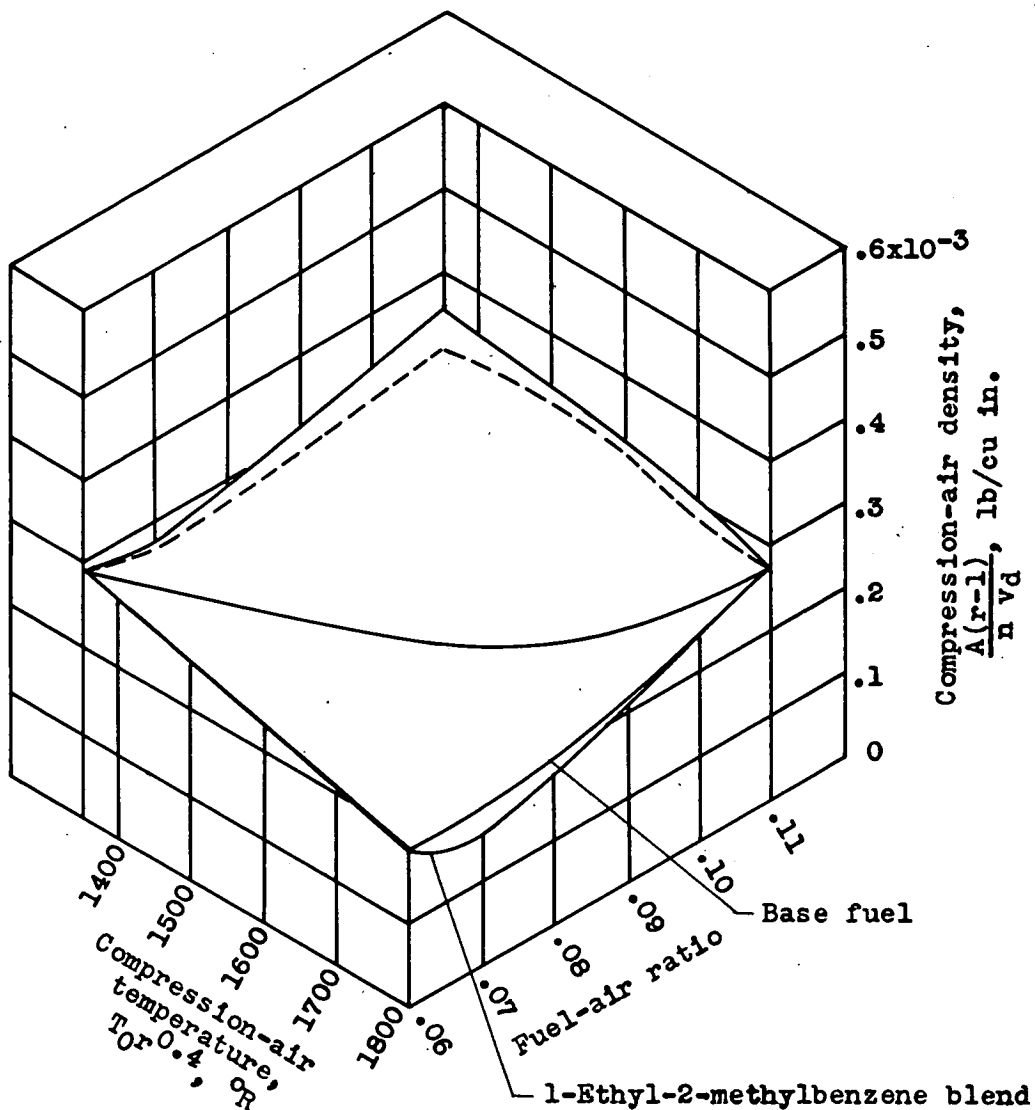
Figure 5. - Concluded. Performance of leaded 25-percent aromatic blends with base fuel consisting of 87.5 percent 8 reference fuel and 12.5 percent n-heptane plus 4 ml TEL per gallon in modified CFR engine. Engine speed, 1800 rpm; spark advance, 20° B.T.O.; coolant, water at 250° F; inlet-air temperature, 250° F; incipient knock.



(a) 1,2,3-Trimethylbenzene.



Figure 6. - Effect of compression temperature and fuel-air ratio on knock-limited compression-air density for 25-percent aromatic blends with base fuel consisting of 87.5 percent S reference fuel and 12.5 percent *n*-heptane plus 4 ml TEL per gallon. Modified CFR engine: compression ratios, 5.0, 6.0, 7.3, 8.7, and 10.0; engine speed, 1800 rpm; spark advance, 20° B.T.C.; coolant, water at 250° F; inlet-air temperature, 250° F; incipient knock.



(b) 1-Ethyl-2-methylbenzene.



Figure 6. - Continued. Effect of compression temperature and fuel-air ratio on knock-limited compression-air density for 25-percent aromatic blends with base fuel consisting of 87.5 percent S reference fuel and 12.5 percent n-heptane plus 4 ml TEL per gallon. Modified CFR engine: compression ratios, 5.0, 6.0, 7.3, 8.7, and 10.0; engine speed, 1800 rpm; spark advance, 20° B.T.C.; coolant, water at 250° F; inlet-air temperature, 250° F; incipient knock.

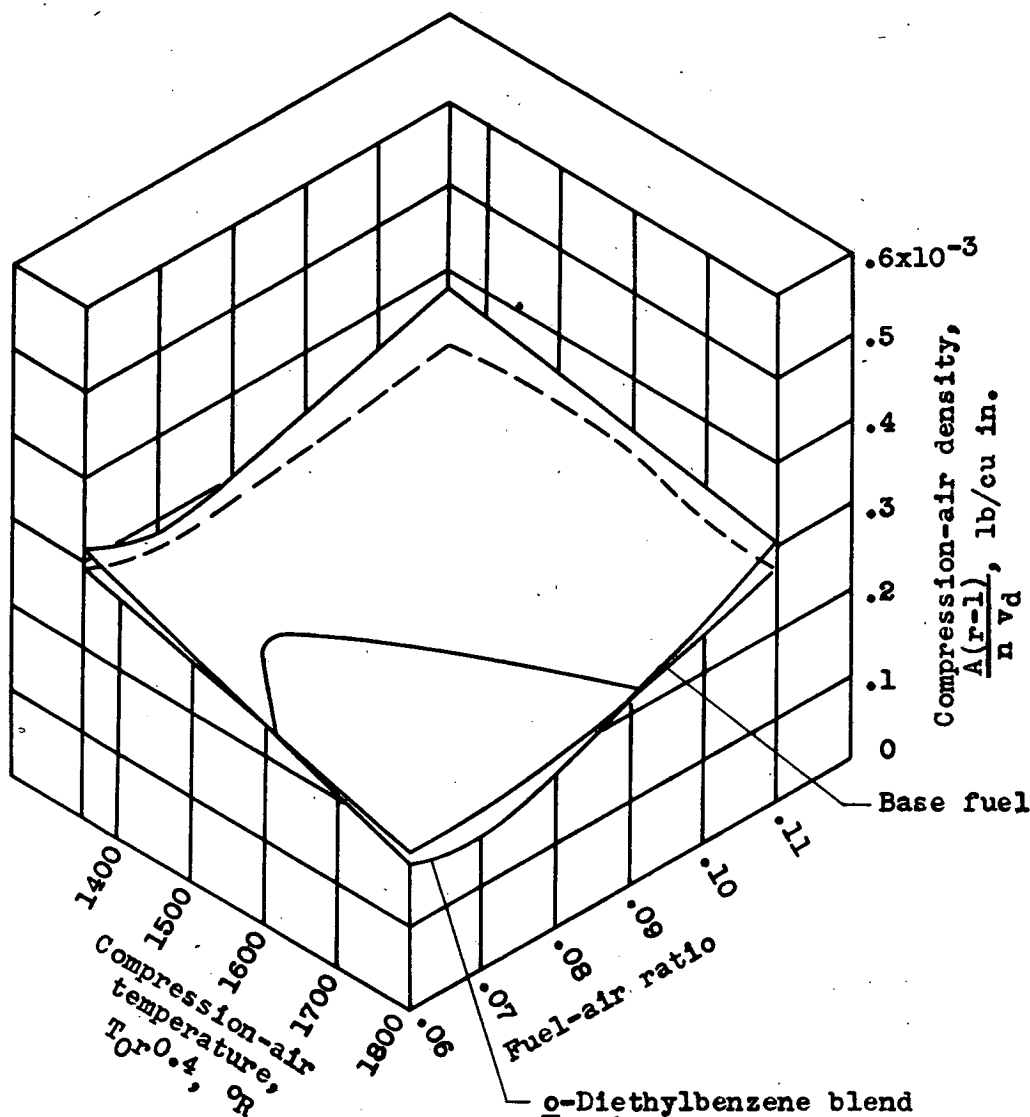
(c) *o*-Diethylbenzene.

Figure 6. - Continued. Effect of compression temperature and fuel-air ratio on knock-limited compression-air density for 25-percent aromatic blends with base fuel consisting of 87.5 percent S reference fuel and 12.5 percent *n*-heptane plus 4 ml TEL per gallon. Modified CFR engine: compression ratios, 5.0, 6.0, 7.3, 8.7, and 10.0; engine speed, 1800 rpm; spark advance, 20° B.T.C.; coolant, water at 250° F; inlet-air temperature, 250° F; incipient knock.

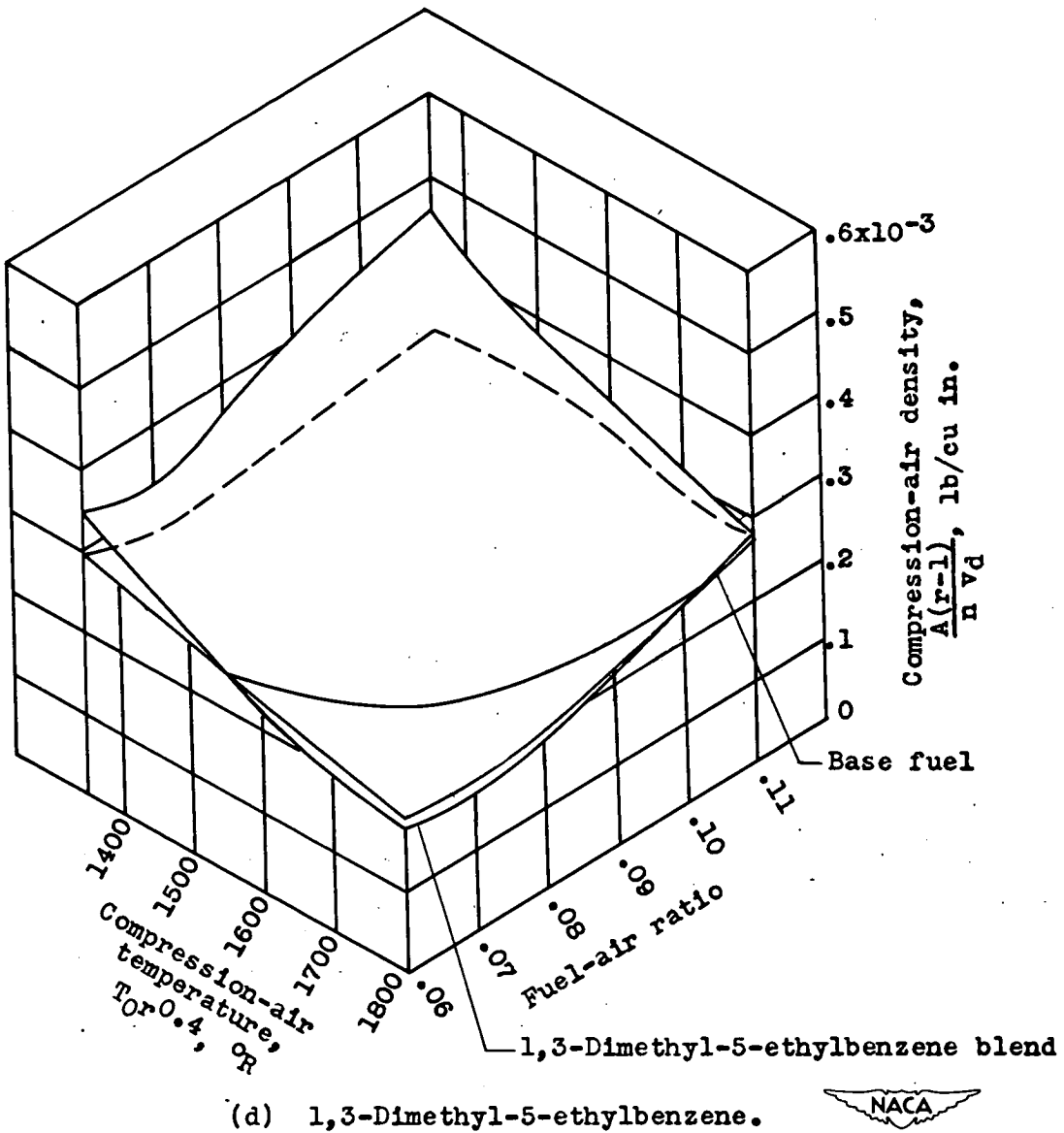
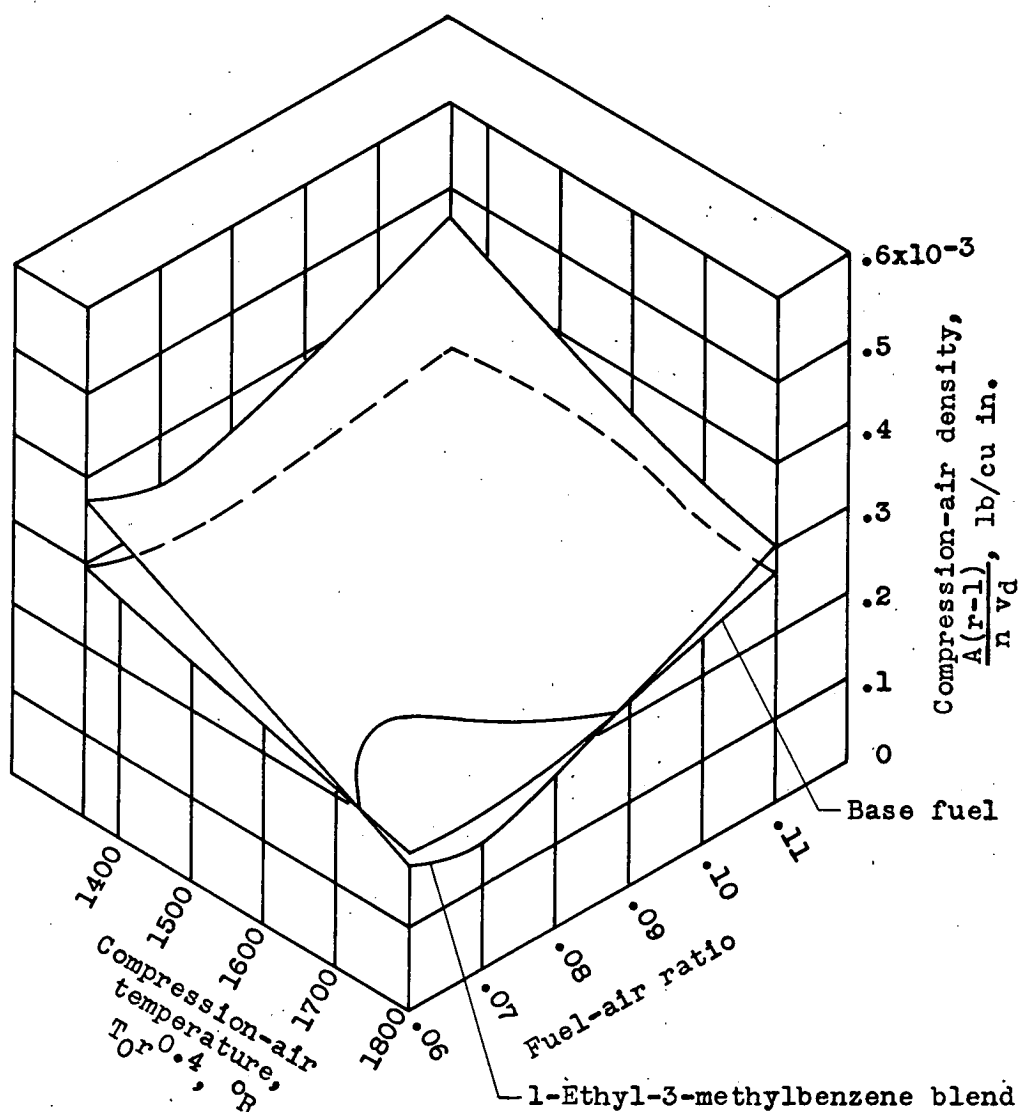


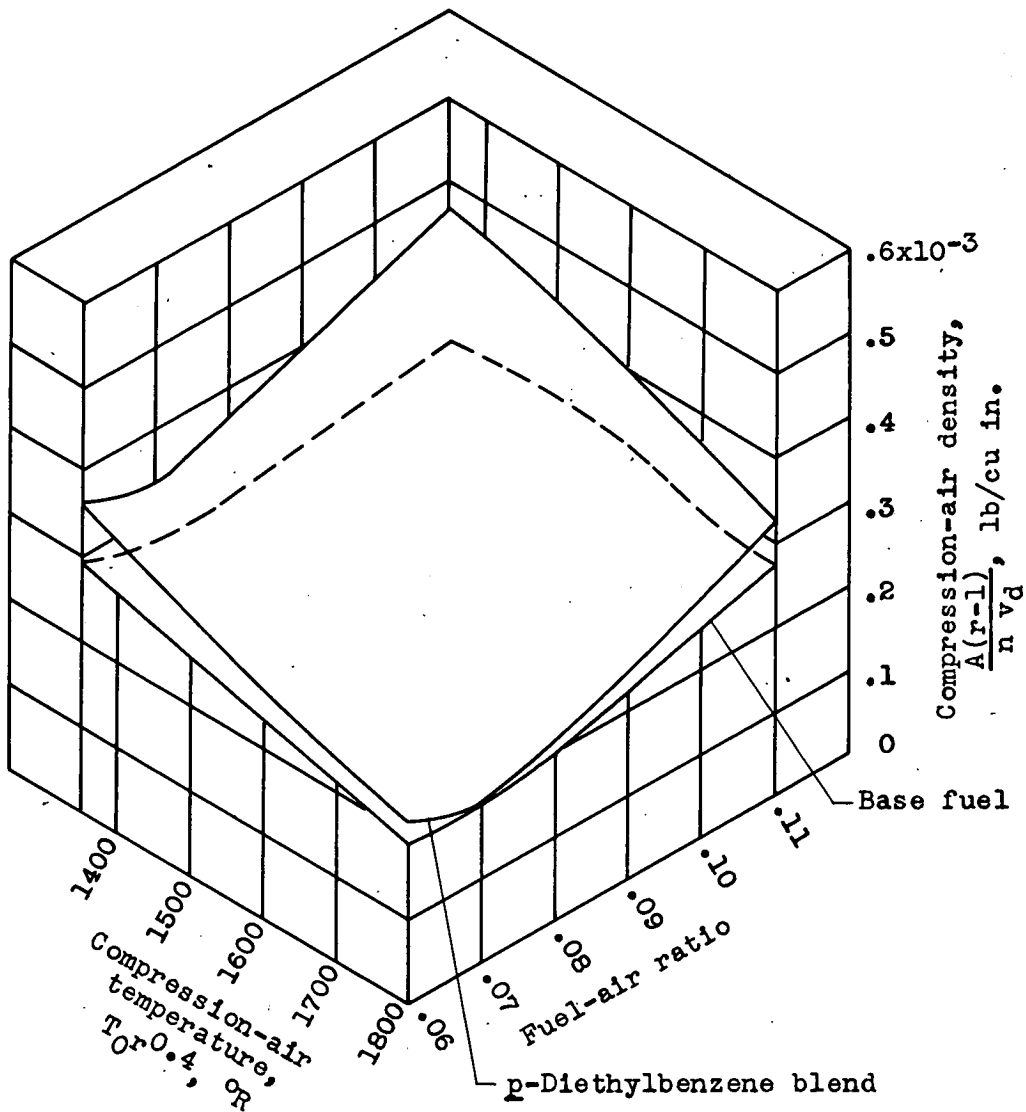
Figure 6. - Continued. Effect of compression temperature and fuel-air ratio on knock-limited compression-air density for 25-percent aromatic blends with base fuel consisting of 87.5 percent S reference fuel and 12.5 percent *n*-heptane plus 4 ml TEL per gallon. Modified CFR engine: compression ratios, 5.0, 6.0, 7.3, 8.7, and 10.0; engine speed, 1800 rpm; spark advance, 20° B.T.C.; coolant, water at 250° F; inlet-air temperature, 250° F; incipient knock.



(e) 1-Ethyl-3-methylbenzene.



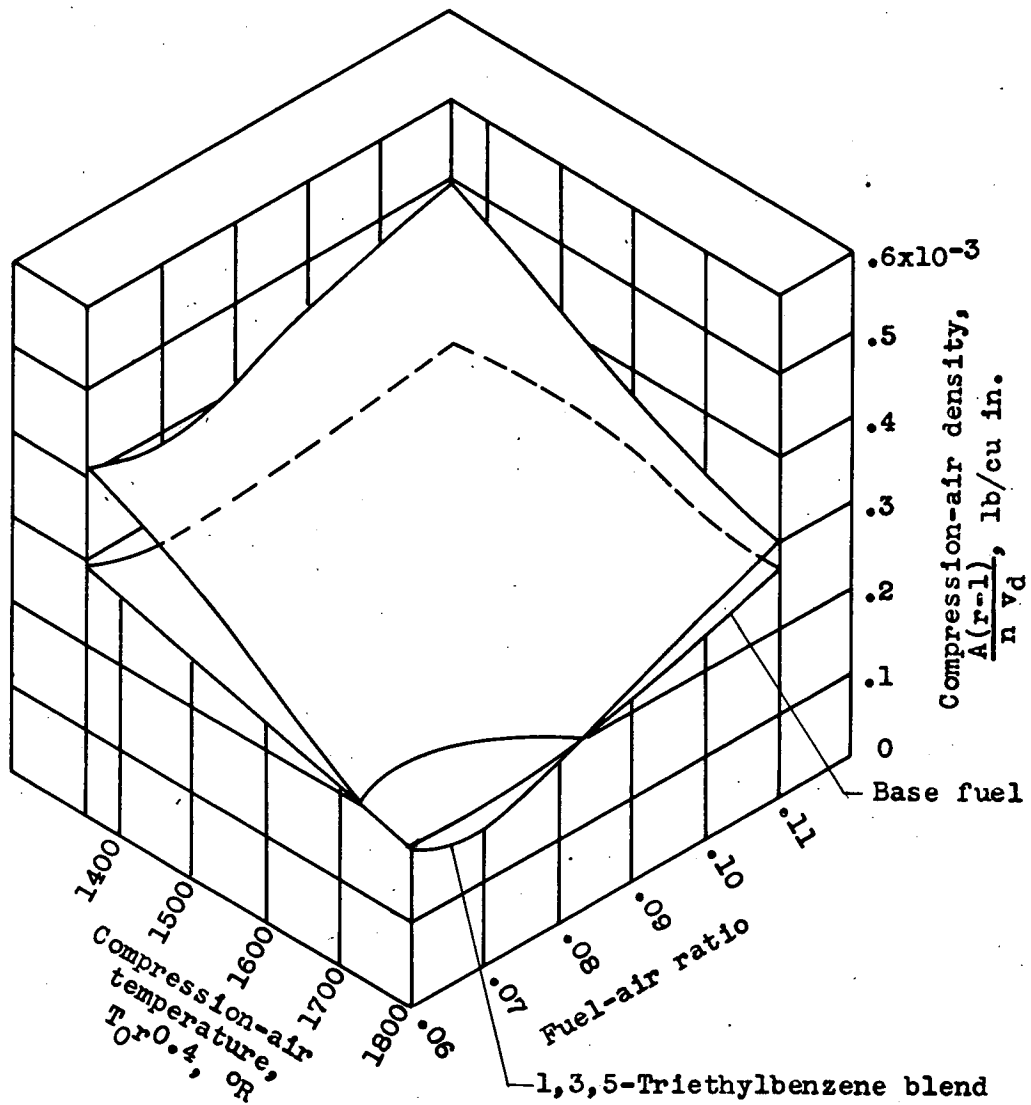
Figure 6. - Continued. Effect of compression temperature and fuel-air ratio on knock-limited compression-air density for 25-percent aromatic blends with base fuel consisting of 87.5 percent S reference fuel and 12.5 percent n-heptane plus 4 ml TEL per gallon. Modified CFR engine: compression ratios, 5.0, 6.0, 7.3, 8.7, and 10.0; engine speed, 1800 rpm; spark advance, 20° B.T.C.; coolant, water at 250° F; inlet-air temperature, 250° F; incipient knock.



(f) p-Diethylbenzene.



Figure 6. - Continued. Effect of compression temperature and fuel-air ratio on knock-limited compression-air density for 25-percent aromatic blends with base fuel consisting of 87.5 percent S reference fuel and 12.5 percent *n*-heptane plus 4 ml TEL per gallon. Modified CFR engine: compression ratios, 5.0, 6.0, 7.3, 8.7, and 10.0; engine speed, 1800 rpm; spark advance, 20° B.T.C.; coolant, water at 250° F; inlet-air temperature, 250° F; incipient knock.



(g) 1,3,5-Triethylbenzene.



Figure 6. - Continued. Effect of compression temperature and fuel-air ratio on knock-limited compression-air density for 25-percent aromatic blends with base fuel consisting of 87.5 percent S reference fuel and 12.5 percent *n*-heptane plus 4 ml TEL per gallon. Modified CFR engine: compression ratios, 5.0, 6.0, 7.3, 8.7, and 10.0; engine speed, 1800 rpm; spark advance, 20° B.T.C.; coolant, water at 250° F; inlet-air temperature, 250° F; incipient knock.

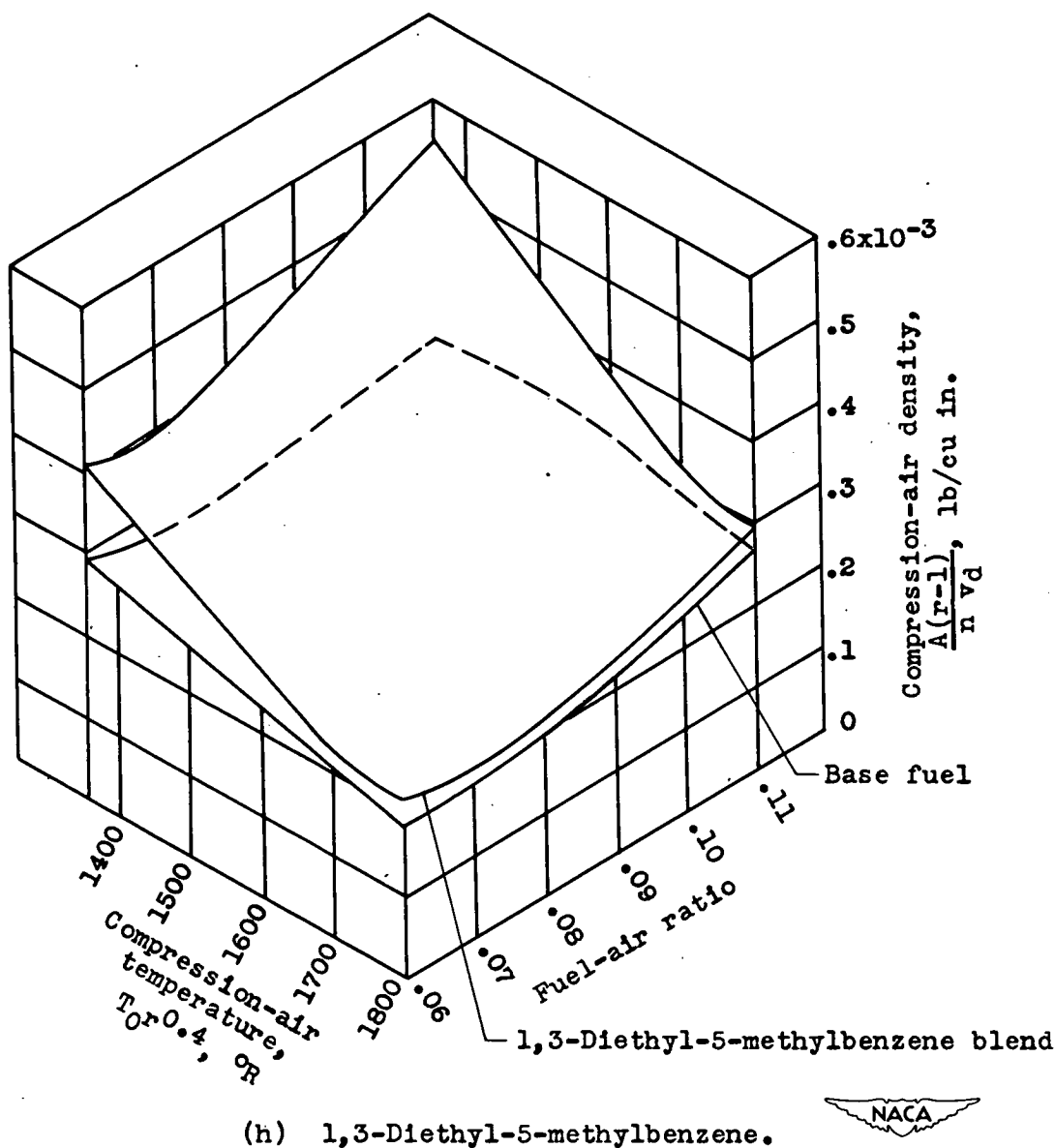
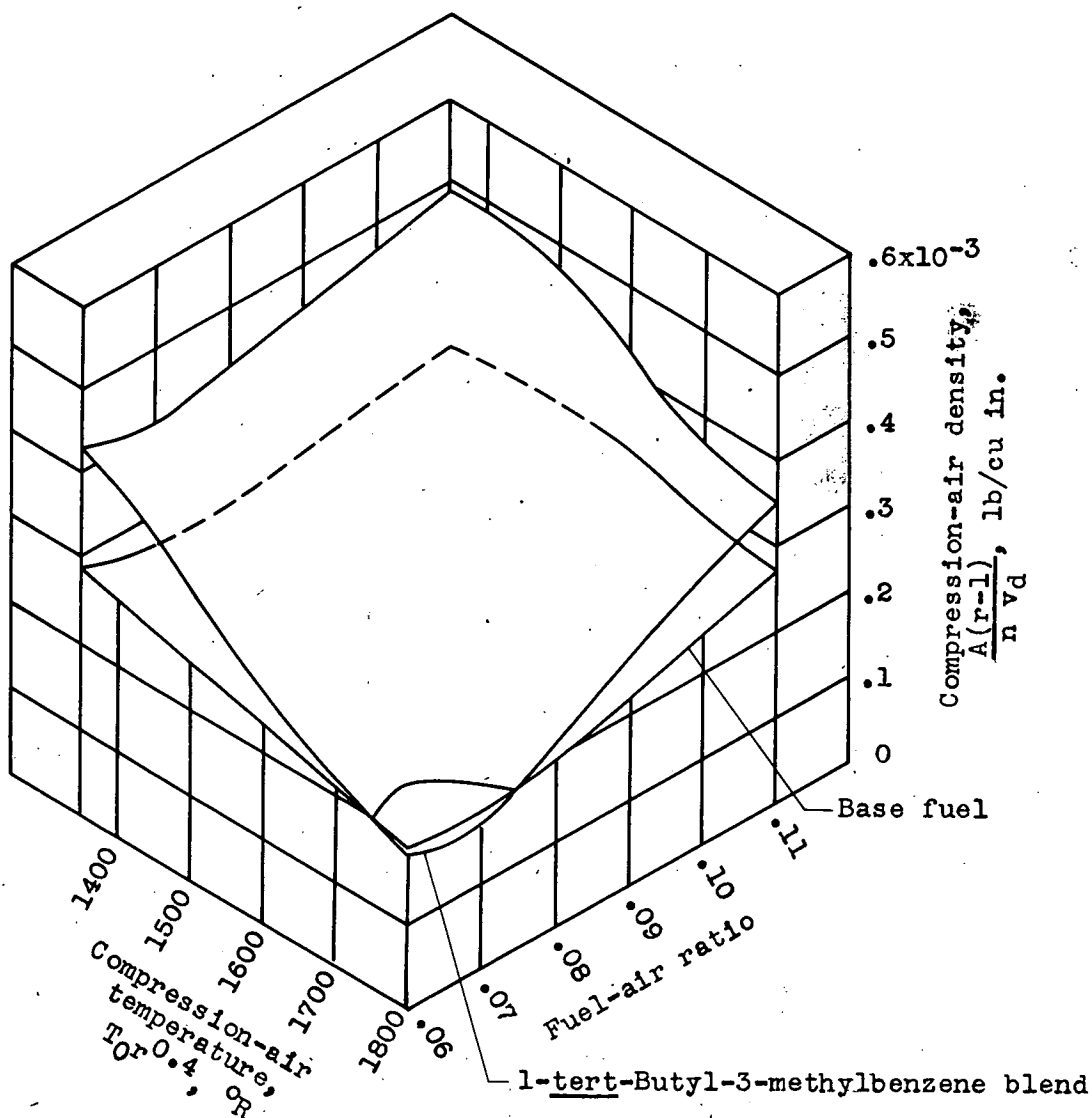


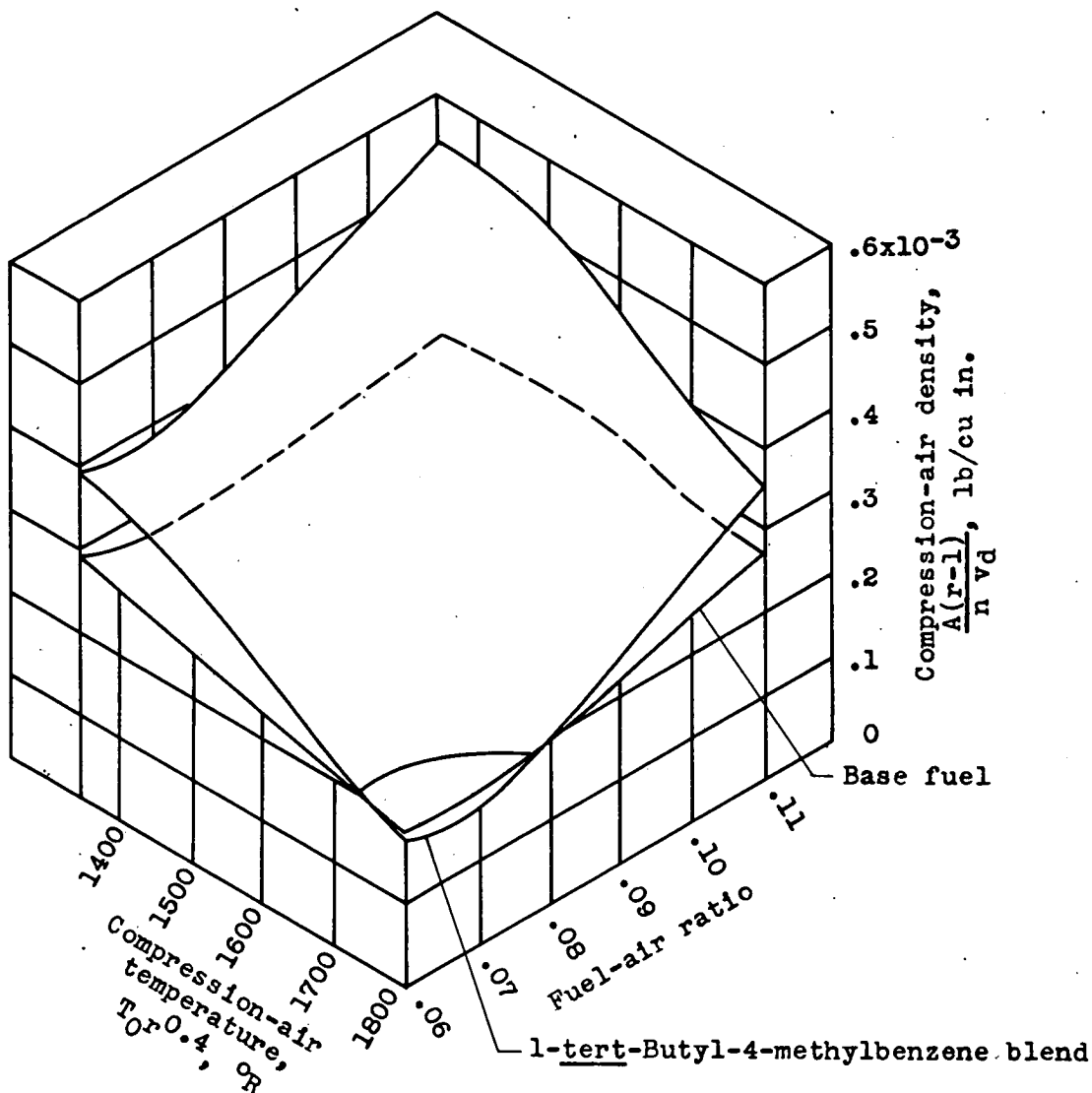
Figure 6. - Continued. Effect of compression temperature and fuel-air ratio on knock-limited compression-air density for 25-percent aromatic blends with base fuel consisting of 87.5 percent S reference fuel and 12.5 percent *n*-heptane plus 4 ml TEL per gallon. Modified CFR engine: compression ratios, 5.0, 6.0, 7.3, 8.7, and 10.0; engine speed, 1800 rpm; spark advance, 20° B.T.C.; coolant, water at 250° F; inlet-air temperature, 250° F; incipient knock.



(i) 1-tert-Butyl-3-methylbenzene.



Figure 6. - Continued. Effect of compression temperature and fuel-air ratio on knock-limited compression-air density for 25-percent aromatic blends with base fuel consisting of 87.5 percent S reference fuel and 12.5 percent *n*-heptane plus 4 ml TEL per gallon. Modified CFR engine: compression ratios, 5.0, 6.0, 7.3, 8.7, and 10.0; engine speed, 1800 rpm; spark advance, 20° B.T.C.; coolant, water at 250° F; inlet-air temperature, 250° F; incipient knock.



(j) 1-tert-Butyl-4-methylbenzene.



Figure 6. - Concluded. Effect of compression temperature and fuel-air ratio on knock-limited compression-air density for 25-percent aromatic blends with base fuel consisting of 87.5 percent S reference fuel and 12.5 percent n-heptane plus 4 ml TEL per gallon. Modified CFR engine: compression ratios, 5.0, 6.0, 7.3, 8.7, and 10.0; engine speed, 1800 rpm; spark advance, 20° B.T.C.; coolant, water at 250° F; inlet-air temperature, 250° F; incipient knock.